Assessment of Impacts from the Hart-Miller Dredged Material Containment Facility, Maryland.

Year 17 Technical Report (July 1998 – April 2000)

Prepared by:

Maryland Department of the Environment

(in cooperation with the agencies below)

Chesapeake Biological Laboratory · Solomons

PORT OF 1706 BALTIMORE

Maryland Department of Natural Resources

MDE

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CONVERSION FACTORS[1]

WEIGHT:

1Kg = 1000g = 2.205 lbs.
1g = 1000mg = 2.205 x 10^{-3}lbs
1mg = 1000μg = 2.205 x 10^{-3}lbs

1 lb = 16oz = 0.454Kg

LENGTH:

1m = 100cm = 3.281ft = 39.370in
1cm = 10mm = 0.394in
1mm = 1000μm = 0.039in

1ft = 12in = 0.348m

CONCENTRATION:

1ppm = 1mg/L = 1mg/Kg = 1μg/g = 1mL/m^3
1g/cc = 1Kg/L = 8.345 lbs/gallon
1g/m^3 = 1mg/L = 6.243 x 10^{-5}lbs/ft^3

1 lb/gal = 7.481 lbs/ft^3 = 0.120g/cc = 119.826g/L = 119.826Kg/m^3
1oz/gal = 7.489Kg/m^3

VOLUME:

1L = 1000mL
1mL = 1000μL
1cc = 10^{-6} m^3

1yd^3 = 27ft^3 = 764.560L = 0.764m^3
1acre-ft = 1233.482m^3
1 gallon = 3785cc
1ft^3 = 0.028m^3 = 28.317L

FLOW:

1m/s = 196.850ft/min = 3.281ft/s
1m^3/s = 35.320ft^3/s

1ft^3/s = 1699.011L/min = 28.317L/s
1ft^2/hr = 2.778 x $10^{-4}$$ft^2$/s = 2.581 x $10^{-5}$$m^2$/s
1ft/s = 0.031m/s
1yd^3/min = 0.45ft^3/s
1yd^3/s = 202gal/s = 764.560L/s

AREA:

1m^2 = 10.764ft^2
1hectare = 10000m^2 = 2.471acres

1ft^2 = 0.093m^2
1acre = 4046.856m^2 = 0.405 hectares

[1] Modified from the June 1994 Draft "Evaluation of Dredged Material Proposed for Discharge in Waters of the U.S. – Testing Manual" published by the U.S. Environmental Protection Agency and the U.S. Army Corp of Engineers.

LIST OF ACRONYMS

AAS - Atomic Absorption Spectrometry

AVS - Acid Volatile Sulfide

BAF - Bioaccumulation Factor

BCF - Bioconcentration Factor

CBL - Chesapeake Biological Laboratory

CDF – Confined Disposal Facility

COC - Citizens' Oversight Committee

COMAR - Code of Maryland Regulations

CWA - Clean Water Act

DCAD - Dredging Coordination and Assessment Division

DGPS - Differential Global Positioning System

DMCF – Dredged Material Containment Facility

EF - Enrichment Factor

ERL - Effects Range Low

ERM - Effects Range Median

GC - Gas Chromatography

GFAAS - Graphite Furnace Atomic Absorption Spectrometry

HMI - Hart -Miller Island Dredged Material Containment Facility

ICAP- Inductively Coupled Argon Plasma

LBP - Lipid Bioaccumulation Potential

MDE - Maryland Department of the Environment

MGS - Maryland Geological Survey

MLW - Mean Low Water

MS - Mass Spectrometry

NBS - National Bureau of Standards

NIST - National Institute of Standards and Technology

NOAA - National Oceanic and Atmospheric Administration

NRC - National Research Council of Canada

PAH - Polynuclear Aromatic Hydrocarbons

PCB - Polychlorinated Biphenyl

ppb - Parts per billion

ppm - Parts per million

ppt - Parts per thousand

QA - Quality Assurance

QC - Quality Control

SOP - Standard Operating Procedure

SRM - Standard Reference Material

TARSA - Technical and Regulatory Services Administration

TBP - Theoretical Bioaccumulation Potential

TDL - Target Detection Limit

TOC - Total Organic Carbon

TRC - Technical Review Committee

UMCES - University of Maryland Center for Environmental Science

USACE - U.S. Army Corps of Engineers

EPA - United States Environmental Protection Agency

WQC - Water Quality Certification

WQS - Water Quality Standards

CHAPTER 1: PROJECT MANAGEMENTAND SCIENTIFIC/TECHNICAL COORDINATION (Project 1)
MONITORING YEAR 17 (September 1998 – April 2000)

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ACKNOWLEDGMENTS

Year 17 of the Hart-Miller Island Exterior Monitoring Program would not have been successful without the help of several Technical and Regulatory Services Administration (TARSA) staff members, including: Mr. George Harman, Chairman; Mr. Visty P. Dalal, past Chairman; Mr. Matthew Rowe, Technical Coordinator/Budget Manager; Mr. Nathaniel Brown, past Budget Manager; Ms. Ellen Lathrop-Davis and Ms. Karen Eason, Environmental Specialists. The Chairman was responsible for making sure that the project work was done efficiently, in a coordinated manner, and met all the technical goals set by the Technical Review Committee for Year 17. The Technical Coordinator wrote the Project I sections of the HMI reports, standardized the data and technical reports among projects, conducted data management, and facilitated the peer review process. The Budget Manager was responsible for ensuring that all project related deliverables and invoices were received from each PI and accounted for through a budgetary tracking system. The Environmental Specialists provided insightful comments and conducted peer review of the data and technical reports.

The Maryland Department of the Environment would like to thank all the members of the HMI Exterior Monitoring Program's Technical Review Committee and the HMI Citizens' Oversight Committee for their helpful comments and suggestions throughout the project year. Special thanks to the Maryland Port Administration, under the auspices of the Maryland Department of Transportation, for their continued commitment to and support of the HMI Exterior Monitoring Program. The efforts and cooperation of Ms. Ellen Lathrop-Davis, Dr. Robert Mason and Dr. Jim Hill, the Principal Investigators for each project in the Year 17 monitoring effort, were greatly appreciated. Appreciation is also reserved for Dr. Steve Storms and Mr. Shane Moore of the Maryland Environmental Service (MES), who provided information on the dredged material inputs to HMI for Year 17.

Lastly, thanks to Dr. Robert Summers, Director, Mr. Narendra Panday and Dr. Richard Eskin, of TARSA, for their guidance, suggestions, and commitment to the Hart-Miller Island Exterior Monitoring Program.

INTRODUCTION

It is no surprise that our nation's capital lies in such close proximity to the shores of the Chesapeake. The Bay's 2,300 square miles of tidal surface waters are a living protein factory, which provided the nation's early settlers with an unlimited supply of food. As the third most productive fishery in the U.S. today, Chesapeake Bay still supplies 90% of the nation's blue crab (*Callinectes sapidus*) and 70-90% of the Atlantic Coast stock of striped bass (*Morone saxatilis*). The menhaden (*Brevoortia tyrannus*) fishery, over 70% of which is processed in the lower Bay at Reedville, is the largest single-species fishery in the United States.

Food alone, however, was not the only appeal of the Chesapeake to the early colonists. The quiet waters and abundance of sheltered harbors offered protection to the early naval fleets and allowed easy access to ocean-borne commerce. In 1790, Maryland led the nation in ship construction and Baltimore dominated the ship building industry on the Chesapeake. Many naval battles were fought and won on the Chesapeake as far back as the Revolutionary War, the War of 1812, and the Civil War.

A significant portion Maryland's economy is still derived from the Chesapeake's seafood and commercial shipping industries. However, the abundance of shallow water habitat throughout the Chesapeake region, which is so critical to the juvenile stages of many species of fish and shellfish, has also posed navigational challenges to shipping since vessels first plied her waters. The shallow character of the Chesapeake influenced the early architecture of sailboats in the Bay region towards boats with extremely shallow draft and removable keels.

The present day shipping industry is moving towards larger ships with deeper drafts that can accommodate a higher payload of cargo. This trend towards larger and deeper ships calling ports nationwide has forced the Port of Baltimore to develop its own set of deep navigation channels to remain competitive in the both the national and global marketplace. Two to four million cubic yards of material must be dredged annually from Baltimore Harbor and its approaches in order to keep the Port of Baltimore accessible to maritime commerce. Finding suitable placement sites for sediments dredged from these channels remains a challenge for the Port of Baltimore.

Hart-Miller Island Dredged Material Containment Facility

In 1981, and in response to the Maryland Port Administration's need for dredged material placement sites, the Hart-Miller Dredged Material Containment Facility (HMI) was built to contain approximately 52 million cubic yards (MCY) of dredged material. HMI is located approximately 14 miles due east of Baltimore's Inner Harbor and lies at the mouth of Back River in Baltimore County. The facility is encircled by a 29,000-foot long perimeter dike covering an 1,140-acre area. A 4,300 foot long interior cross-dike divides the island into a 300 acre South Cell and an 800 acre North Cell. A series of five spillways are located on the perimeter dike, with spillways 1, 2 and 4 located in the North Cell and spillways 3 and 5 located in the South Cell. The spillways are designed to release the excess water (i.e., supernatant) used to pump dredged material from barges into the facility.

The dike around HMI's six-mile perimeter were raised from +18 feet above mean low water (MLW) to +28 feet in 1988, to provide sufficient capacity for the 50-foot channel deepening project. The site was subsequently filled to capacity in June 1996. In October 1996, the dike surrounding the North Cell was raised another 16 feet, to +44 feet MLW, increasing site capacity by 30 MCY and extending the facility's operational life another 12 years. Total site capacity is currently estimated to be 100 MCY. Volumes and project names for dredged materials placed at HMI during monitoring Year 17 are provided in Table 1-1.

Table 1-1: Total cubic yards of dredged material placed during Year 17 of monitoring at HMI (7/98 – 6/99).

Dredging Projects	Cubic Yards of Material Placed at HMI
CRAIGHILL CHANNEL	306,789
CRAIGHILL UPPER	73,293
CUTOFF ANGLE	673,324
BREWERTON CHANNEL	172,898
BREWERTON ANGLE	499,496
WEST CHANNEL	102,982
BREWERTON EXTENSION	767,743
TOLCHESTER CHANNEL	322,362
NORTH LOCUST POINT	13,870
DUNDALK TERMINAL	40,502
CONSOLIDATING COAL	28,595
MIDDLE RIVER - SUE CREEK	8,730
MIDDLE RIVER - NORMANS CREEK	34,482
LYNCH COVE	2,187
GRAND TOTAL	**3,047,253**

The last inflow of dredged material into the South Cell was completed on October 12, 1990. The process of converting the 300-acre South Cell into a wildlife refuge is currently underway. The North Cell is projected to reach full capacity by the year 2009, at which time it will also be converted to wildlife refuge. The remnants of Hart and Miller Islands, which lie outside the dike, serve as a State park and receive heavy recreational use throughout the summer months.

Environmental Monitoring

It was recognized prior to construction that any adverse impacts to the Bay's fishery resources or water quality from HMI could affect facility operations. Under Section 404(b&c) of the Clean Water Act (1987), entitled "Permits for Dredged or Fill Material", permits for dredged material disposal can be rescinded if it is determined that: "the discharge of such materials into such area will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas."[4] In

[4] From page 250 of the 1987 Clean Water Act published by the Water Pollution Control Federation.

accordance with this federal mandate and as a special condition of State Wetlands License 72-127(R), a long-term compliance monitoring program was implemented in 1981 to assess the effects of HMI on the surrounding environment. Results from the monitoring are used to detect changes from baseline environmental conditions in the area surrounding HMI, and, if necessary, to guide decisions regarding operational changes or remedial actions.

The Hart-Miller Island Exterior Monitoring Program has evolved over the past sixteen years, involving different agencies, monitoring components, sampling times and methods. The baseline studies conducted from 1981-1983 included studies of the water column, currents, submerged aquatic vegetation, fisheries, benthic macroinvertebrates, sediment grain size, sediment geochemistry, and tissue analyses. Some of these projects were discontinued over the years. The following four projects, which have been conducted since the beginning of the monitoring program, are: (1) Project Management and Scientific/Technical Coordination, (2) Sedimentary Environment, (3) Benthic Community Studies, and (4) Analytical Services.

Project I: Project Management and Scientific/Technical Coordination Conducted by the Maryland Department of the Environment (MDE)

During the baseline monitoring years (1981-1983), the Chesapeake Research Consortium was responsible for project management. The Maryland Department of Natural Resources (DNR) was responsible for Project 1 from 1984 to 1995. In 1995, during the Year 15 monitoring effort, project management was transferred from DNR to the Maryland Department of the Environment (MDE). The Environmental Assessment Division (EAD) within the Technical and Regulatory Services Administration (TARSA) of MDE presently coordinates the Hart-Miller Island Exterior Monitoring Program.

Project management entails comprehensive oversight of the HMI Exterior Monitoring Program to ensure coordination between the different projects and principal investigators (PIs). Before a monitoring year begins, EAD reviews draft monitoring proposals for the upcoming year and consults with the PIs concerning sampling stations and analyses. Following approval of the proposals by the Maryland Port Administration (MPA), EAD develops formats and timeframes for receipt of deliverables from the PIs, including seasonal reports, cruise reports, draft technical and data reports, invoices and attendance at quarterly meetings. Budgets for each of the PIs are tracked by MDE and portfolios are distributed to each PI during quarterly meetings.

Upon receipt of the draft data and technical reports, EAD initiates a three-tiered peer review process to solicit technical and other comments on the draft reports. The first level of review is conducted internally by MDE staff knowledgeable in the fields of dredging and environmental risk assessment, including toxicologists, engineers, benthic and aquatic ecologists. The next level of review is performed by the HMI Technical Review Committee (TRC) consisting of researchers/staff from the University of Maryland, and other State and Federal agencies, with knowledge of estuarine ecology and processes. The final tier in the review process is the HMI Citizens' Oversight Committee (COC), watermen's associations and environmental groups, who bring the cares and concerns of Maryland's citizens to bear on the monitoring effort. EAD compiles and organizes the comments received and submits them to the PIs for response.

Lastly, EAD conducts database management, production and standardization of the data and technical reports, and holds quarterly and special meetings among the PIs and the TRC. Project I is an evolving project which strives to constantly improve the scientific merit of the Exterior Monitoring Program and the presentation of the data and technical reports.

Hart-Miller Island Map and Station Designations

Due variation in station numbers and maps used historically to demarcate sampling stations and locations for each HMI project, MDE has standardized the map and sampling stations for Year 17 to promote consistency and comparability between projects and among sampling years. From Year 17 onward, the principal investigators for each project will use the same map with common station designations MDE-1 through MDE- 36 (Figure 1-1). Any new stations added to the HMI project will be prefixed by "MDE" and numbered sequentially, starting from the last highest station number (i.e., MDE-37, MDE-38, MDE-39, etc.). A station conversion table is provided to facilitate comparison with older maps and station designations (Table 1-2).

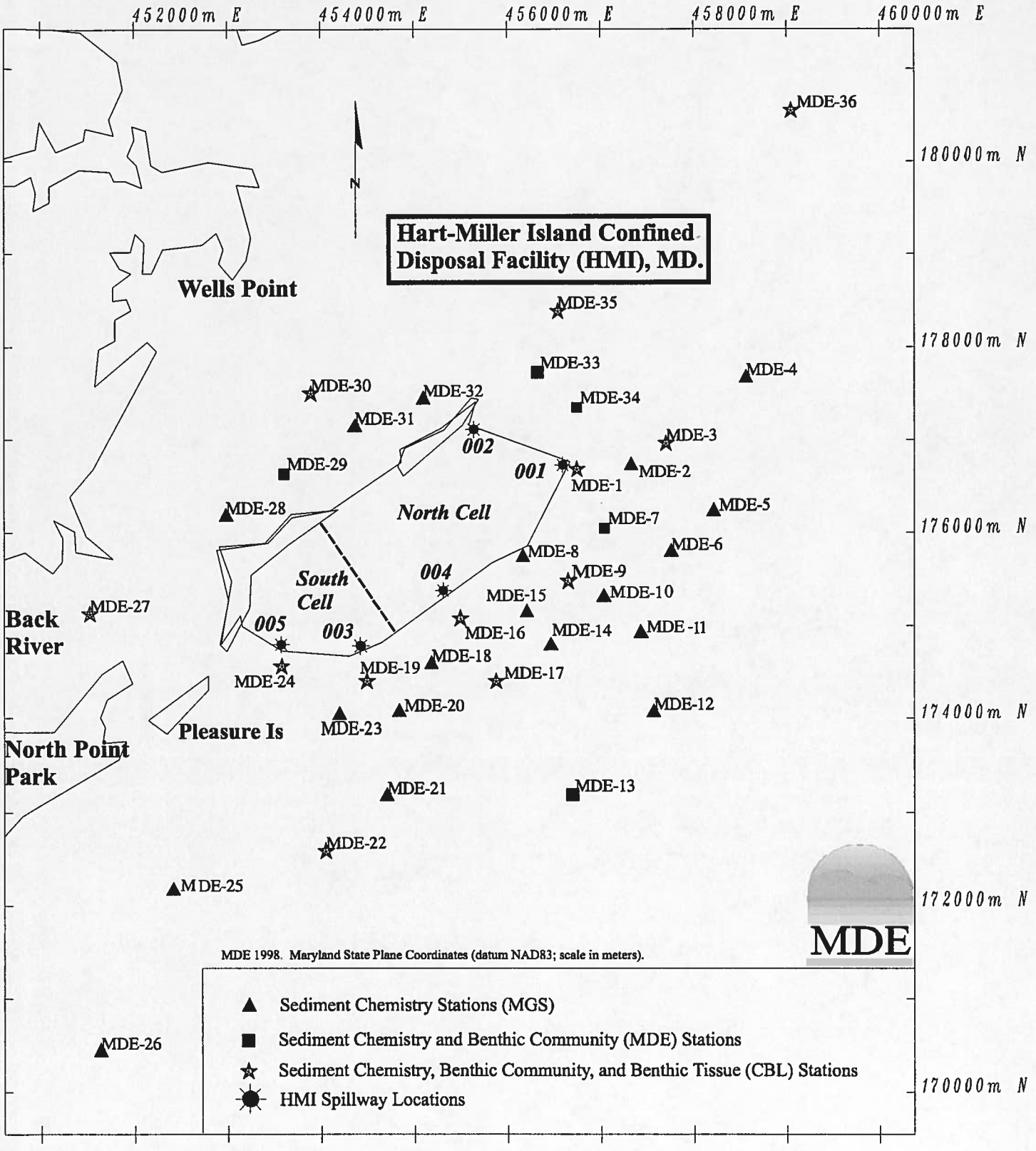

Figure 1-1: Sampling Stations, Hart-Miller Island Exterior Monitoring Study, Year 17. Project II (sediment chemistry) conducted by Maryland Geological Survey (MGS). Project III (benthic community ecology study) conducted by Maryland Department of the Environment (MDE). Project IV (benthic tissue contaminant analysis) conducted by University of Maryland Chesapeake Biological Laboratory (CBL). Map prepared by MDE with assistance from MGS and MES.

Table 1-2: Current HMI station designations developed by MDE along with formerly used MGS and CBL station numbers and 7-digit codes.

Current MDE #	Former MGS #	Former CBL #	MD 7 Digit Code	CBL 7-Digit Code
MDE-1	21-b	S7	XIF5505	XIF5405
MDE-2	11		XIF5501	
MDE-3	28	HM9	XIG5699	XIF5297
MDE-4	BC5	HM7	XIF6388	XIF6388
MDE-5	61		XIG5295	
MDE-6	64		XIG4999	
MDE-7	24		XIF5302	
MDE-8	8-a		XIF5009	
MDE-9	9		XIF4806	
MDE-10	BC4		XIF4703	
MDE-11	71		XIG4501	
MDE-12	30		XIF4000	
MDE-13	31		XIG3506	
MDE-14	25	G25	XIF4405	XIF4405
MDE-15	7		XIF4609	
MDE-16	BC3	S4	XIF4615	XIF4715
MDE-17	BC2	BC-3	XIF4285	
MDE-18	6		XIF4317	
MDE-19	5	G5	XIF4221	XIF4221
MDE-20	26		XIF4016	
MDE-21	19		XIF3620	
MDE-22	34	HM16	XIF3224	XIF3325
MDE-23	BC1		XIF4024	
MDE-24	29		XIF4372	
MDE-25	20		XIF3064	
MDE-26	27		XIF2038	
MDE-27	23	HM26	XIF4642	XIF5145
MDE-28	18		XIF5232	
MDE-29	17		XIF5427	
MDE-30	BC6	BC6	XIF5925	
MDE-31	16		XIF5722	
MDE-32	15		XIF5917	
MDE-33	13		XIF6008	
MDE-34	12		XIF5805	
MDE-35	14		XIF6407	
MDE-36	22	HM22	XIG7589	XIG7689

Project II: Sediment Analyses Conducted by the Maryland Geological Survey (MGS)

With the exception of Year 16, the Maryland Geological Survey has been responsible for monitoring the sediments surrounding HMI since 1981. During Year 17, MGS analyzed sediments for the presence of eight trace metals (iron [Fe], chromium [Cr], nickel [Ni], cadmium [Cd], zinc [Zn], lead [Pb], manganese [Mn], and copper [Cu]). The ancillary parameters of carbon (C), sulfur (S), nitrogen (N), and phosphorus (P) were measured along with sediment grain size and water content.

During Year 17, the metal concentrations detected in sediments surrounding HMI were some of the lowest found since before 1989. Moreover, in contrast to past years, there were no seasonal fluctuations in sediment metal concentrations between the September 1998 and April 1999 cruises for Year 17. Only Zn and Pb were found to be elevated above ambient levels and only then at concentrations below biological effects thresholds.

Carbon, P and N were measured to address concerns about the release of nutrients from the Hart-Miller Island facility. The concentrations of these parameters were compared to Redfield's ratio, the naturally occurring N/P/C ratios occurring in plankton, and adjusted for the higher carbon levels found in the northern Bay. The concentrations of these parameters found in HMI sediments are not elevated above normal background levels for this area of Chesapeake Bay.

The results of the grain size analysis do not show any clear patterns of how sediments behave on a seasonal basis. The complexity of the hydrodynamic environment surrounding HMI as well as the difficulty in sampling the identical spot at a given station between cruises makes sediment grain size analyses particularly difficult. However, the general sediment distribution pattern around HMI is consistent with what has been seen in prior cruises dating back to 1988.

Project III: Benthic Community Studies Conducted by the Maryland Department of the Environment (MDE)

The Maryland Department of the Environment performed the Benthic Community Studies project for Year 17 of monitoring at HMI. All previous benthic community monitoring had been performed by the University of Maryland Center for Environmental Science/ Chesapeake Biological Laboratory (UMCES/CBL). The methods used by MDE were maintained as closely as possible to those used in previous years to preserve the comparability of the data.

Benthic macroinvertebrates were collected twice from 17 stations surrounding HMI and during two separate cruises (September 23rd, 1998 and May 10-11, 1999). A total of 32 benthic macroinvertebrate taxa were collected at these 17 stations. Additionally, the water quality parameters of pH, dissolved oxygen (DO), temperature, conductivity and salinity were measured using a Hydrolab Surveyor II or a Yellow Springs Instruments (YSI) multi-parameter water quality meter. Secchi depths were measured at each station using a standard Secchi disk.

For the third consecutive year, the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI; Weisberg et al. 1997), a multimetric index of community condition, was used to assess the benthic community at each station. The four metrics used in the B-IBI were total infaunal

abundance, relative abundance of pollution-indicative taxa, relative abundance of pollution-sensitive taxa, and the Shannon-Wiener diversity index. Taxa richness and total abundance of all taxa were also calculated but not included in the B-IBI calculations. Only two sites, nearfield station MDE-19 and Back River/Hawk Cove station MDE-27, were considered impaired when rated using the B-IBI. Station MDE-19 is in an area that has been historically subject to prop wash by barge traffic present at HMI. Station MDE-27 is at the mouth of Back River and is more representative of conditions in Back River than around HMI. As in previous years, no significant differences were observed between the nearfield and reference benthic community stations sampled around Hart-Miller Island.

The water quality conditions measured around HMI were in the expected ranges for the time of year during which they were collected. The main differences between the water quality data collected were due to seasonal temperature and salinity changes driven by photoperiod and fluctuating freshwater input from the Susquehanna River.

Project IV: Analysis of Contaminants in Benthic Organisms and Sediments Conducted by the University of Maryland Center for Environmental Science's Chesapeake Biological Laboratory (CBL)

In Year 17, analyses of sediments and tissues were conducted by the Chesapeake Biological Laboratory (CBL) of the University of Maryland Center for Environmental Science. CBL has been involved in the analysis of benthic tissues since Year 14. Field sampling was conducted during September 1998 and April 1999.

Sediments

In Year 17, CBL performed sediment analysis in conjunction with the work performed by MGS. At stations where MGS conducted their sediment metal analyses, CBL analyzed a subsample of the sediments collected by MGS for the additional metal species of mercury (Hg), methylmercury (MMHg), arsenic (As), and silver (Ag). At stations where CBL sampled clam tissues, a sample of the sediment was analyzed for an entire suite of metals (Hg, MMHg, As, Ag, Pb, Cu, Cd, Cr, Zn, and Ni) and for PAHs, PCBs, and organochlorine pesticides. This allowed CBL to make temporal and spatial correlations between the concentrations of contaminants in clams and sediments at a given site.

1. Metals

The analytical technique for metals changed in Year 17 from using Hydride Generation Atomic Absorption Spectrometry to Inductively Coupled Plasma–Mass Spectroscopy (ICP-MS). The range in metal concentrations between the September 1998 and the April 1999 sampling were comparable, with a few exceptions. In April 1999, sediment concentrations of Ag, Cu, Hg and Pb were higher than in September 1998. These differences in metal concentrations, however, are within a factor of three and are not considered significant given the long-term variability of the dataset or the error range of the analytical instrumentation. Also, Ni and As concentrations were higher in 1998 and 1999 than in 1996 or 1997. The As concentration is still within a factor of two between the different years while Ni concentrations were four-fold higher in 1998/1999 compared to 1996/1997. These differences in As and Ni concentrations are most likely a result of the greater sensitivity of the ICP-MS analytical technique.

2. Organics

In 1998 and 1999 the concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in sediment averaged 3260 ng/g and 3070 ng/g dry weight, respectively. PAHs are not enriched above regional background levels at any of the stations immediately adjacent to HMI. The average total PAH concentration is approximately 2.5 times the geometric mean concentration of total PAHs in northern mainstem Chesapeake Bay sediments above the Potomac River mouth (Nakanishi 1996). HMI PAH concentrations, however, are orders of magnitude lower than the concentrations measured in surficial sediments in the adjacent Baltimore Harbor and Back River systems. Total Polychlorinated Biphenyl (PCB) concentrations in sediments averaged 61 ng/g dry weight in 1998 and 56 ng/g dry weight in 1999.

Clams

Every other monitoring year, CBL measures tissue burdens of contaminants (metals and organics) in the clam *Rangia cuneata.* Clams were collected from twelve sites and eleven sites during the September 1998 and April 1999 cruises, respectively.

1. Metals

Of the ten metals tested for in clam tissues, mercury (Hg) and methylmercury (MMHg) concentrations were the lowest at less than 20 ng/g. Silver (Ag), arsenic (As), cadmium (Cd) and lead (Pb) were also low at less than 5 μg/g. Chromium (Cr), copper (Cu) and nickel (Ni) concentrations were higher, ranging from 10 to 50 μg/g. Zinc concentrations were highest at 140 μg/g.

The concentrations of metals found in clams from HMI were compared to metals in clams from Poplar Island, MD and Galveston Bay, TX. Metal concentrations in clams from HMI were slightly higher than, but still comparable to a another species of clam from Poplar Island and lower than the concentrations found in clams from Galveston Bay. These results put metal concentrations in HMI clams at low to moderate levels. The possibility of contamination of clams from Back River or Baltimore Harbor sources will be explored in future studies.

2. Organics

The concentrations of polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and pesticides were also examined in clams from the Hart-Miller Island region. The concentrations of all of these compounds were well below thresholds of concern. These results suggest that HMI is not a source of organic pollution to benthic macroinvertebrates surrounding the facility.

CHAPTER II: SEDIMENTARY ENVIRONMENT YEAR 17 TECHNICAL REPORT (Project 2) September 1998 - April 2000

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ACKNOWLEDGMENTS

For their assistance during the Fall 1998 sampling cruise, we would like to thank the Maryland Department of the Environment for providing the research vessel Thomas C. Hopkins, Jr. and the following people for piloting the research vessel and collecting samples: Billy Evans, Ellen Lathrop-Davis, Jonathan Stewart, and Gil Lookingland. We would also like to thank the Spring 1999 crew: Rick Younger, captain of the R/V Kerhin (formerly the R/V Discovery), and our colleagues at the Maryland Geological Survey, Rich Ortt and Geoff Wikel. In addition to MGS staff members, we extend our thanks to Stephen Storms at MES, who provided us with much of the information related to site operations.

EXECUTIVE SUMMARY

The Coastal and Estuarine Geology Program of the Maryland Geological Survey (MGS) has been involved in monitoring the physical and chemical behavior of near-surface sediments around the Hart-Miller Island Dredged Material Containment Facility (HMI) since its planning stages. As part of the exterior monitoring program for Year 17, bottom sediment samples from 36 sites were collected on September 21, 1998 and April 29, 1999. The samples were analyzed for both physical and chemical parameters. The physical parameters analyzed were sediment water content and particle grain size (Sand, Silt, Clay). Based on these analyses, bulk density was calculated and the Pjerup's class determined. The chemical parameters measured in sediments were total elemental concentrations of the following: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), cadmium (Cd), lead (Pb), phosphorus (P), carbon (C), nitrogen (N), and sulfur (S).

The grain size distributions of Year 17 sediment samples do not show any clear trends. This is due to the complexity of the environmental conditions and source of material to the area. However, the general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of effluent release from the spillways at HMI).

Discharge from HMI apparently does not leave a C, N or P signature in the exterior sediments. This is based on the use of Redfield's Ratio, data from the main stem Bay and the distribution pattern of these elements around the facility. However, this does not mean that there may not be significant discharge of nutrients into the Bay from HMI. Nutrients discharged in a dissolved or suspended phase that do not settle quickly in the area adjacent to the facility would not be detected in sediments.

During Year 17, metal concentrations in the area influenced by HMI are some of the lowest since elevated levels were first noted in 1989, and Spring cruise levels are only slightly elevated from the Fall. Samples from all but three stations for both cruises were within the levels considered normal baseline concentrations. Two stations which are attributable to HMI have slightly elevated levels of metals and a southernmost station, which may be influenced by proximity to Baltimore Harbor, was also elevated. The minimal influence of HMI during Year 17 can be attributed to facility operations. Although there were significant periods where the discharge rates dropped below 10 million gallons per day (MGD), acidic conditions did not form. Consequently, leaching of the sediment was minimized and the rate of acid formation was greatly reduced. Chromium, Cu, Ni, Pb and Zn were found in concentrations that exceed the ERL values, and Zn and Ni exceeded the ERM values. However, when the data were normalized, only Zn and Pb were found to be significantly enriched compared to the baseline. Based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Persistent elevated metal levels in sediments around HMI indicate a need for continued

monitoring. Even though the dike has nearly reached its capacity and the volume of effluent is expected to decline, dewatering of the contained material may lead to higher metal levels in the effluent. Exposure of dredged material to the atmosphere is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long term sediment load in the Bay. Although these levels are much lower than any biological effects threshold, continued monitoring is needed to detect if the levels increase to a point where action is required. In addition, monitoring is required to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing contained dredged material to the atmosphere. Close cooperation with MES will be important in this endeavor.

It is further recommended that additional sampling sites be added south of the facility to assess the influence of Baltimore Harbor on the HMI exterior sediments. Sites in the southern portion of the study area have consistently shown elevated metal levels. It has been suggested that the elevated levels are from Baltimore Harbor, but no spatially contiguous record exists which links these two areas. Additional sites would provide adequate spatial coverage to measure a gradient from the Harbor to HMI.

INTRODUCTION

Since 1981, the Maryland Geological Survey (MGS) has monitored the sedimentary environment in the vicinity of Hart-Miller Island Dredged Material Containment Facility (HMI). HMI is a man-made enclosure in northern Chesapeake Bay, named for the two natural islands that form part of its western perimeter (Figure 2-1). Designed specifically to contain material dredged from Baltimore Harbor and its approach channels, the oblong structure was constructed of sediment dredged from the dike interior. The physical and geochemical properties of the older, "pristine" sediment used in dike construction differed from those of modern sediments accumulating around the island. Likewise, material dredged from shipping channels and deposited inside the facility also differs from recently deposited sediments in the region. Much of the material generated by channel deepening is fine-grained and enriched in trace metals and organic constituents. In addition, oxidation of the sediment placed in the dike during dewatering and crust management produces effluent enriched in metals. These differences in sediment properties and discharge from the facility have allowed the detection of changes attributable to construction and operation of the dike.

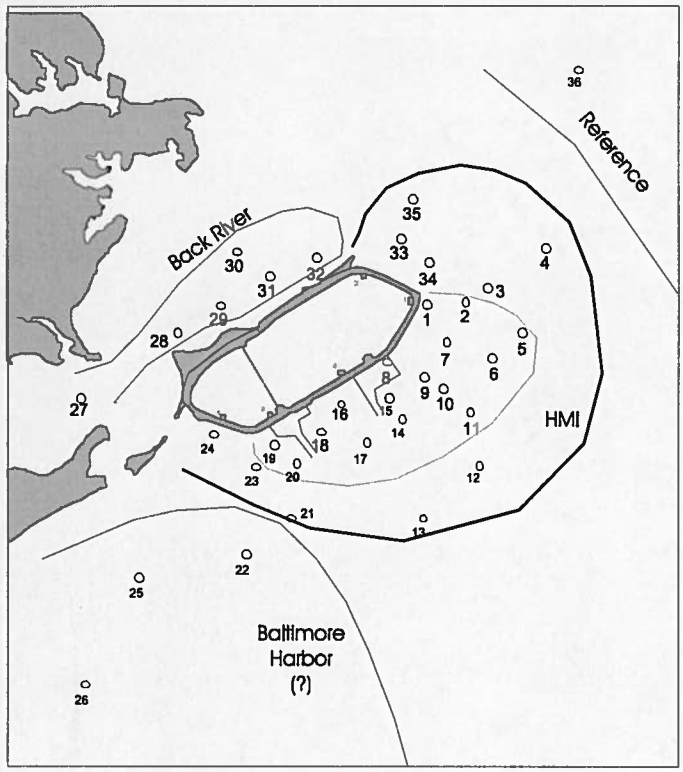

Figure 2-1: Sampling locations for Year 17. Contours show zones of influence found in previous studies.

Previous Work

Events in the history of the facility can be meaningfully grouped into the following periods:

1. Preconstruction (Summer 1981 and earlier)
2. Construction (Fall 1981 - Winter 1983)
3. Post-construction
    a. Pre-discharge (Spring 1984 - Fall 1986)
    b. Post-discharge (Fall 1986 - present).

The nature of the sedimentary environment prior to and during dike construction has been well-documented in earlier reports (Kerhin et al. 1982a, l982b; Wells and Kerhin 1983; Wells et

al. 1984; Wells and Kerhin 1985). This work established a baseline against which changes due to operation of the dike could be measured. The most notable effect of dike construction on the surrounding sedimentary environment was the deposition of a thick, light gray to pink layer of "fluid mud" immediately southeast of the facility.

For a number of years after HMI began operating, no major changes were observed in the surrounding sedimentary environment. Then, in April 1989, more than two years after the first release of effluent from the facility, anomalously high Zn values were detected in samples collected near spillway #1 (Hennessee et al. 1990b). Zn levels rose, from the regional average enrichment factor of 3.2 to 5.5. Enrichment factors are ratios of concentrations, in this case Zn to Fe, which are then normalized to the same ratio in a standard reference material. Comparison of the normalized values with the measured values of interest allows the determination of impairment by pollution. Effluent discharged during normal operation of the dike was thought to be the probable source of Zn accumulation in sediments. This was confirmed by use of the Upper Bay Model (Wang 1993), a numerical, hydrodynamic model, which was used to predict the dispersion of discharge from the facility, coupled with discharge records from the spillways. From the discharge records it was noted that there is a significant increase in metal loading to the exterior sediments during periods of low discharge (<10MGD); periods of higher discharge rates corresponded to lower metal levels in the exterior sediments.

The factors which influence the metals loadings to the exterior sediments are circulation patterns in the northern Bay and the rate and nature of discharge from the facility. The results of the hydrodynamic model pertinent to a discussion of contaminant distribution around HMI follow (see the *10th Year Interpretive Report* for details):

1. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike.

2. Releases from Spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal concentrations to the east and southeast of the facility.

   Releases from Spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from Spillways #1 and #4 because of the lower shearing and straining motions away from the influence of the gyre.

3. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike.

4. Discharge from the HMI spillways has no influence on the circulation gyre. This

was determined by simulating point discharges of 0-70 million gallons/day (MGD) from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the dike; the higher the discharge, the higher the concentration in the plume outside the dike.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, but it does not explain why the level of Zn in the sediments increases at lower discharges. To account for this behavior, the chemistry of the effluent discharged from the dike was examined, as reported in the *11th Year Interpretive Report*. As a result of this examination, a model was constructed that predicts the general trend in the behavior of Zn as a function of discharge rate from the dike. The model has two components: (1) loading due to material similar to the sediment in place and (2) loading of enriched material as predicted from a regression line based on discharge data supplied by the Maryland Environmental Service (MES). The behavior of this model supports the hypothesis of metal contamination during low flow conditions. Sediments discharged from the facility are the source of metals that enrich the exterior sediments. When exposed to the atmosphere, these sediments oxidize in a process analogous to acid mine drainage (i.e., sulfide minerals oxidize to produce sulfuric acid, which leaches acid-soluble metals, nutrients, and organic compounds that are released with the discharged waters).

Since the initial detection of Zn, the size of the affected area has fluctuated, as have metal concentrations within the area. Nonetheless, higher than expected Zn levels persisted through Year 17 in the vicinity of the dike.

Dike Operations

Certain activities associated with the operation of HMI have a direct impact on the exterior sedimentary environment. Local Bay floor sediments appear to be sensitive, both physically and geochemically, to the release of effluent from the dike. Events or operational decisions that affect the quality or quantity of effluent discharged from the dike account for some of the changes in exterior sediment properties observed over time. For this reason, dike operations during the periods preceding each of the Year 17 cruises are summarized below. Information was extracted from *Operations Reports* prepared by MES, covering the periods April 1, 1998 - April 30, 1999; a detailed synopsis of this period and digital discharge records were provided to MGS for this report by MES (pers. com. Storm).

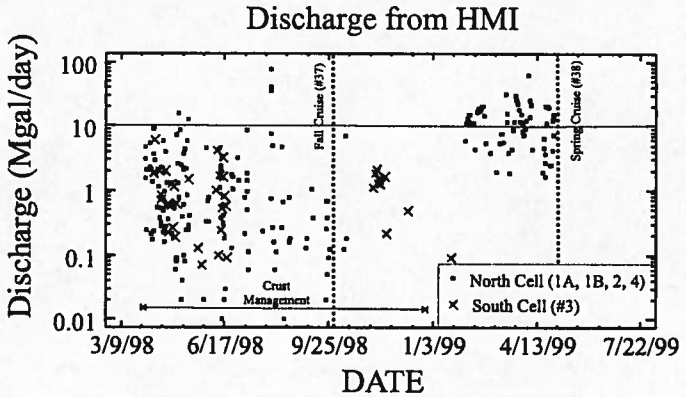

Figure 2-2: Discharge from the spillways at HMI for all spillways; grouped by cell location. The cruise dates are denoted by vertical dotted lines, and the 10Mgal/day discharge shown as a horizontal line.

In the period prior to the September sampling cruise the primary emphasis of dike operations was dewatering and crust management. No dredging operations were completed in this period. This is reflected in the low discharge rates from the spillways as shown in Figure 2-2. As noted in previous reports and shown in Figure 2-3, low discharge rates are accompanied by more acidic conditions.

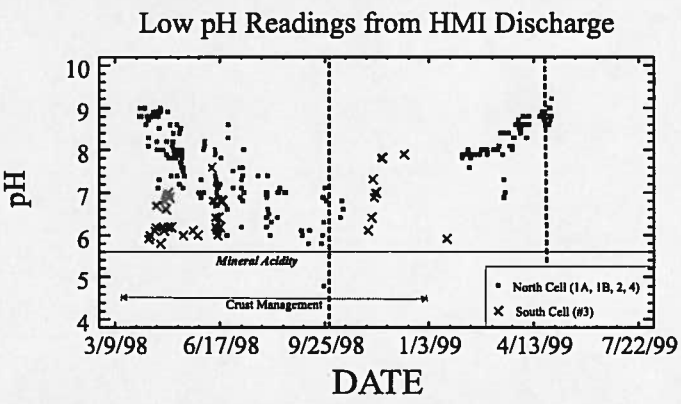

Figure 2-3: Low pH measured for daily discharge from HMI. Data is divided between North and South Cell spillways. Vertical lines denote sampling cruise dates. pH readings below the horizontal line indicates free mineral acidity.

The April 1999 cruise followed a period of active placement of sediments in HMI. There were ten dredging operations active prior to sampling, depositing a total of >2.9 million cubic yards (MCY) of material. This is reflected in the higher discharge rates and an increase in pH.

The effluent was in compliance with the discharge permit for the entire monitoring period. An interesting feature to note in the discharge records is that even though the flow dropped below the 10 MGD level, where it would be expected to have increased metals discharge, the discharge did not develop free mineral acidity as in previous years. Free mineral acidity is an important condition for leaching of metals from the contained sediments.

OBJECTIVES

As in the past, the main objectives of the Year 17 study were (1) to measure specific physical and geochemical properties of near-surface sediments around HMI and (2) to assess detected changes in the sedimentary environment. Tracking the extent and persistence of the area having historically elevated Zn concentrations was again of particular interest.

METHODS AND MATERIALS

Field Methods

The information presented in this report is based on observations and analyses of sediment samples collected on two cruises during Year 17 of exterior monitoring. The first cruise, on September 21, 1998, took place aboard the R/V Thomas C. Hopkins, Jr.; the second, on April 29, 1999, aboard the R/V Kerhin.

During the first cruise of the year, sampling sites (Figure 2-1) were located in the field by means of a Garmin differential global positioning system (GPS). According to the manufacturer's specifications, the repeatability of the navigation system -- the ability to return to a location at which a navigation fix has previously been obtained -- is better than 10 m (33 ft);

the actual accuracy is an estimated 3-5 m (10-16 ft) (Evans, W., pers. comm.).

During the second cruise, sampling sites were located by means of a Leica MX-300 GPS equipped with an MX50-R Coast Guard Differential Beacon Receiver. The accuracy of that unit is 1-3 m (3-10 ft). That level of accuracy applies only when a vessel re-occupies a station with an identical navigation fix. Actual sample locations seldom coincide precisely with target locations. During the second cruise, aboard the R/V Discovery, the captain estimated that the vessel was within 10 m (33 ft) of the targeted location (Younger, R., pers. comm.). The target coordinates (latitude and longitude -- North American Datum of 1983) of Year 17 sample locations are reported in the *Year 17 Data Report.*

A revised sampling plan, consisting of 36 (Figure 2-1) surficial sediment samples, was developed by the Maryland Department of the Environment (MDE) in conjunction with the monitoring agencies. During the September 1998 cruise, undisturbed samples of the sediments near the sediment-water interface were obtained with a Van Veen sampler. At least one grab sample was collected at each station and split for textural, trace metal, and carbon-sulfur-nitrogen (CSN) analyses. With the research vessel anchored, triplicate grab samples were collected at two stations (MDE-9 and MDE-31). At 24 stations, samples were collected for Chesapeake Biological Laboratory's (CBL) analysis of a second suite of trace metals. (Irregularities in sample collection resulted in the elimination of samples retrieved from MDE-5 and MDE-6.) Upon collection, each sediment sample was described lithologically and subsampled.

During the April 1999 cruise, undisturbed samples of the sediments were obtained with a dip-galvanized Petersen sampler. A minimum of one grab sample was collected at each station and split for textural, trace metal, and CSN analyses. Triplicate grab samples were collected at four stations (MDE-2, MDE-7, MDE-9, and MDE-31). At each station, samples were also collected for CBL's analysis of a second suite of trace metals. Again, each sediment sample was described lithologically before it was sub-sampled. Field descriptions of samples are included in the *Year 17 Data Report.*

Sediment, trace metal, and CSN sub-samples were collected using plastic scoops rinsed with de-ionized water. These sub-samples were taken several centimeters from the top[2], below the flocculent layer, and away from the sides of the sampler to avoid possible contamination from the Van Veen sampler. They were placed in 18-oz Whirl-Pak™ bags. Samples designated for textural and CSN analysis were stored out of direct sunlight at ambient temperatures. Those intended for trace metal analyses were cooled in an ice chest or refrigerator on board the research vessel and maintained at 4°C until they could be processed in the laboratory.

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[2]CBL's samples were collected near the sediment-water interface and included the flocculent layer, when such a layer was present. Those samples were stored in sampling containers supplied by CBL and cooled in an ice chest or freezer on board the research vessel.

Laboratory Procedures

Textural Analyses

In the laboratory, sub-samples from both the surficial grabs and gravity cores were analyzed for water content and grain size composition (sand-silt-clay content). Water content was calculated as the percentage of the water weight to the total weight of the wet sediment:

$$Wc = \frac{Ww}{Wt} \times 100 \qquad (1)$$

where: Wc = water content (%)
Ww = weight of water (g)
Wt = weight of wet sediment (g)

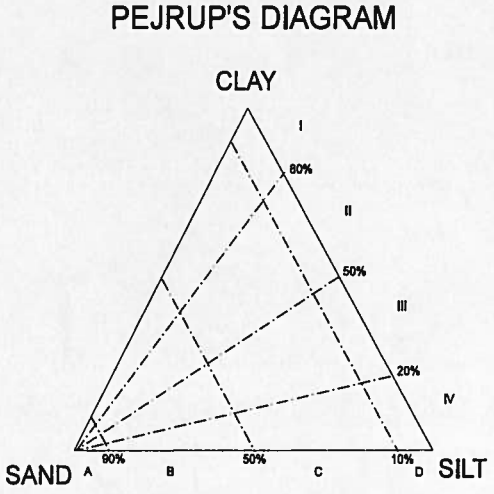

Figure 2-4: Pejrup's (1988) classification of sediment type.

Water weight was determined by weighing approximately 25 g of the wet sample, drying the sediment at 65°C, and reweighing it. The difference between total wet weight (Wt) and dry weight equals water weight (Ww). Bulk density was also determined from water content measurements.

The relative proportions of sand, silt, and clay were determined using the sedimentological procedures described in Kerhin et al. (1988). The sediment samples were pre-treated with hydrochloric acid and hydrogen peroxide to remove carbonate and organic matter, respectively. Then the samples were wet sieved through a 62-um mesh to separate the sand from the mud (silt plus clay) fraction. The finer fraction was analyzed using the pipette method to determine the silt and clay components (Blatt et al. 1980). Each fraction was weighed; percent sand, silt, and clay were determined; and the sediments were categorized according to Pejrup's (1988) classification (Figure 2-4).

Pejrup's diagram, developed specifically for estuarine sediments, is a tool for graphing a three-component system summing to 100%. Lines paralleling the side of the triangle opposite the sand apex indicate the percentage of sand. Each of the lines fanning out from the sand apex represents a constant clay:mud ratio (the proportion of clay in the mud, or fine, fraction). Class names consist of letter-Roman numeral combinations. Class D-II, for example, includes all samples with less than 10% sand and a clay:mud ratio between 0.50 and 0.80.

The primary advantage of Pejrup's classification system over other schemes is that the clay:mud ratio can be used as a simple indicator of hydrodynamic conditions during

sedimentation. (Here, hydrodynamic conditions refer to the combined effect of current velocity, wave turbulence, and water depth.) The higher the clay:mud ratio, the quieter the depositional environment. Sand content cannot be similarly used as an indicator of depositional environment; however, it is well-suited to a rough textural classification of sediment.

Although the classification scheme is useful in reducing a three-component system to a single term, the arbitrarily defined boundaries separating classes sometimes create artificial differences between similar samples. Samples may be assigned to different categories, not because of marked differences in sand-silt-clay composition, but because they fall close to, but on opposite sides of, a class boundary. To avoid that problem, the results of grain size analysis are discussed in terms of percent sand and clay:mud ratios, not Pejrup's classes themselves.

Trace Metal Analysis

Sediment solids were analyzed for eight trace metals, including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and cadmium (Cd). In addition to the trace metals, total phosphorus (P) was analyzed. Samples were digested using a microwave digestion technique followed by analysis on an Inductively Coupled Argon Plasma Spectrometer (ICAP). The digestion method was modified from USEPA Method #3051 in order to achieve total recovery of the elements analyzed. The MGS laboratory followed the steps below in handling and preparing trace metal samples:

1. Samples were homogenized in the Whirl-Pak™ bags in which they were stored and refrigerated (4°C);

2. Approximately 10 g of wet sample were transferred to Teflon evaporating dishes and dried overnight at 105-110°C;

3. Dried samples were hand-ground with an agate mortar and pestle, powdered in a ball mill, and stored in Whirl-Pak™ bags;

4. 0.5000 ± 0.0005 g of dried, ground sample was weighed and transferred to a Teflon digestion vessel;

5. 2.5 ml concentrated nitric acid (HNO_3 :trace metal grade), 7.5 ml concentrated hydrochloric acid (HCl: trace metal grade), and 1 ml ultra-pure water were added to the Teflon vessel;

6. The vessel was capped with a Teflon seal, and the top was hand tightened. Between four and twelve vessels were placed in the microwave carousel;

7. Samples were irradiated using programmed steps appropriate for the number of samples in the carousel. These steps were optimized based on pressure and percent power. The samples were brought to a temperature of 175°C in 5.5 minutes, then

8. Vessels were cooled to room temperature and uncapped. The contents were transferred to a 100 ml volumetric flask, and high purity water was added to bring the volume to 100 ml. The dissolved samples were transferred to polyethylene bottles and stored for analysis; and

9. The sample was analyzed.

All surfaces that came into contact with the samples were acid washed (3 days 1:1 HNO_3; 3 days 1:1 HCl), rinsed six times in high purity water (less than 5 mega-ohms), and stored in high-purity water until use.

The dissolved samples were analyzed with a Jarrel-Ash AtomScan 25 sequential ICAP spectrometer using the method of bracketing standards (Van Loon 1980). The instrumental parameters used to determine the solution concentrations were the recommended, standard ICAP conditions given in the Jarrel-Ash manuals, optimized using standard reference materials (SRM) from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada. Blanks were run every 12 samples, and SRM's were run five times every 24 samples.

Results of the analyses of three SRM's (NIST-SRM #1646 - Estuarine Sediment; NIST-SRM #2704 - Buffalo River Sediment; National Research Council of Canada #PACS-1 - Marine Sediment) are given in Table 2-1. The microwave/ICAP method has recoveries (accuracies) within ±5% for all of the metals analyzed, except Mn. Although poorer, the recoveries for Mn are good. The poorer recoveries for Ni and Mn are due to the concentrations of these elements being near detection limits. The SRM's have unrealistically low concentrations compared to the samples around HMI.

Table 2-1: Results of MGS's analysis of three standard reference materials, showing recovery of the certified metals of interest.

	Percent Recovery		*(n=15)*
Metal	**NIST 1646**	**Buffalo River**	**PACS**
Fe	93±4	99±2	92±3
Mn	93±6	83±4	79±5
Zn	100±1	90±1	101±2
Cu	99±5	96±4	101±2
Cr	96±4	115±5	101±4
Ni	93±9	105±9	89±8
Cd	98±9	*Below Detection*	*Below Detection*
Pb	92±3	87±4	100±5

Carbon-Sulfur-Nitrogen Analysis

Sediments were analyzed for total nitrogen, carbon and sulfur (CNS) contents using a Carlo Erba NA1500 analyzer. This analyzer uses complete combustion of the sample followed by separation and analysis of the resulting gasses by gas chromatographic techniques employing a thermal conductivity detector. The NA1500 Analyzer is configured for CNS analysis using the manufacturer's recommended settings. As a primary standard, 5-chloro- 4-hydroxy- 3-methoxy-benzylisothiourea phosphate is used. Blanks (tin capsules containing only vanadium pentoxide) were run at the beginning of the analyses and after 12 to 15 unknowns (samples) and standards. Replicates of every fifth sample are run. As a secondary standard, a NIST reference material (NIST SRM #1646 - Estuarine Sediment) is run after every 6 to 7 sediment samples. The recovery of the SRM is excellent with the agreement between the NIST certified values and MGS's results well within the one standard deviation of replicate analyses.

RESULTS AND DISCUSSION

Sediment Distribution

The grain size composition (proportions of sand, silt, and clay) of the Year 17 sediment samples is depicted in ternary diagrams based on Pejrup's classification of sediment type (Figure 2-5). One diagram shows the composition of sediments collected during the September 1998 cruise, and the other, the April 1999 cruise. Within a diagram, each solid circle represents one sediment sample. Related statistics, by cruise, are presented in Table 2-2.

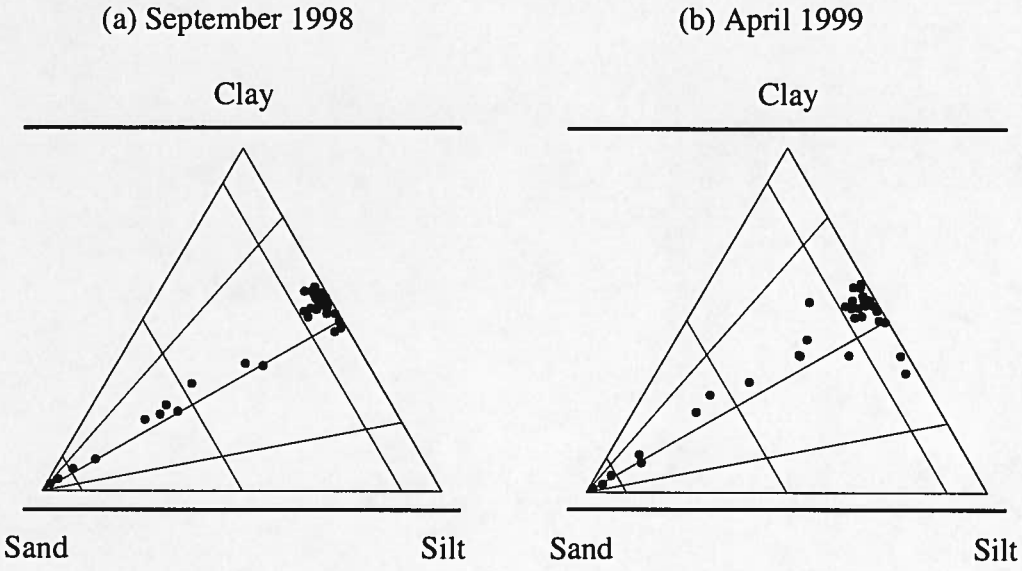

Figure 2-5: Ternary diagrams showing the grain size composition of sediment samples collected in (a) September 1998 and (b) April 1999.

The ternary diagrams show similar distributions of sediment type. Samples range widely in composition, from very sandy (>90% sand) to very muddy (<10% sand). Muddy sediments predominate; about two-thirds of the samples contain less than 10% sand. Points fall fairly close to the line that extends from the sand apex and bisects the opposite side of the triangle (clay:mud = 0.50). In general, points lie above the 0.50 line, indicating that the fine (muddy) fraction of the sediments tends to be somewhat richer in clay than in silt.

Although the two diagrams are similar, they are not identical. The most notable difference is that clay:mud ratios varied over a wider range in April 1999 than they did in September 1998. This broader range is reflected in the summary statistics shown in Table 2-2. The range of clay:mud ratios in September 1998 was 0.15, compared to 0.30 the following spring. Presumably, certain localities (see below) were somewhat quieter (more clay-rich) in April 1999, while others were somewhat more turbulent (more silt-rich) than they had been the previous fall.

Table 2-2: Summary statistics for Year 17 sediment samples.

Variable	September 1998 (Cruise 37)	April 1999 (Cruise 38)
Sand content (%)		
Mean	23.34	21.88
Median	3.68	5.52
Minimum	0.77	0.71
Maximum	96.94	97.73
Range	96.17	97.02
Clay:mud ratio		
Mean	0.56	0.55
Median	0.57	0.56
Minimum	0.48	0.36
Maximum	0.63	0.66
Range	0.15	0.30
Number of samples	33	36

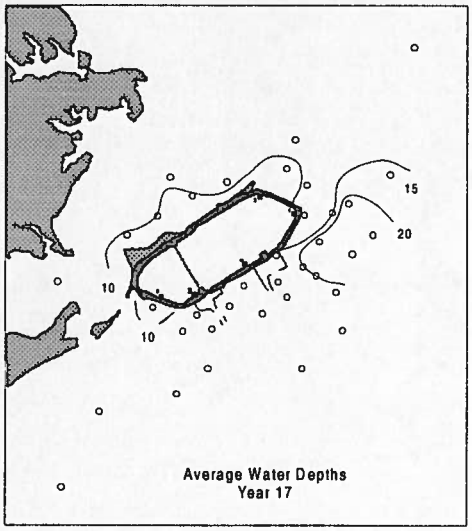

Figure 2-6: Average water depths.

For the two Year 17 cruises, the grain-size distribution of bottom sediments around HMI is depicted in contour maps showing the percentage of sand in bottom sediments and clay:mud ratios. In Figure 2-7 three contour levels represent 10%, 50%, and 90% sand, coinciding with the parallel lines in Pejrup's diagram. Generally, sand content diminishes with distance from HMI. Scattered around the perimeter of the dike, the sandiest sediments (>50% sand), are confined to relatively shallow (<15 ft) waters (Figure 2-6). Broadest north and west of the facility, the shoals are the erosional remains of a larger landmass. The once continuous landmass

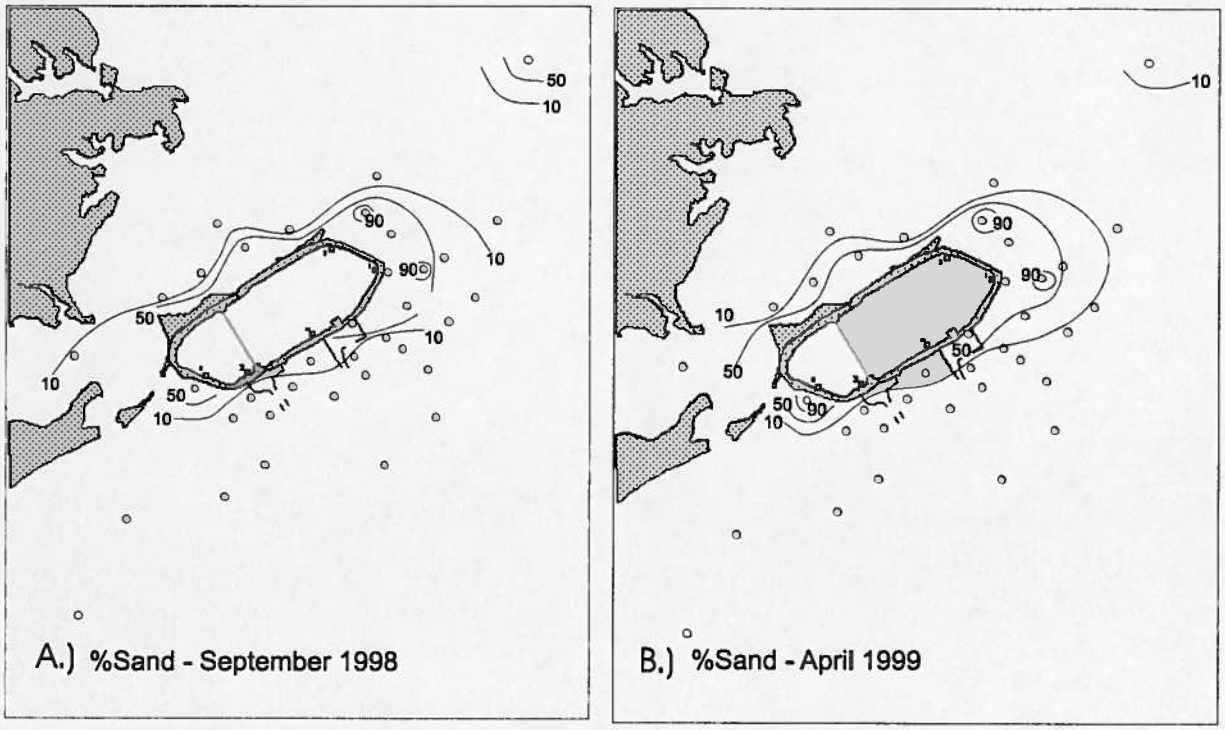

Figure 2-7: Percent Sand distribution for Year 17.

has been reduced to a series of islands, including Hart and Miller, extending from the peninsula that forms the south shore of Back River. However, not all shallow water samples are sandy. In particular, several of the shallow water samples from Hawk Cove (e.g., MDE-28, MDE-30, and MDE-32) contain less than 10% sand.

Sand distribution maps for the two Year 17 cruises are similar in appearance. In fact, in reviewing the results of earlier monitoring years, the distribution of sand around HMI has remained largely unchanged since November 1988, two years following the first release of discharge from the dike.

Over time, clay:mud ratios have tended to be more variable in their distribution. Year 17 was no exception (Figure 2-8). In September 1998, the fine fraction of the sediment was coarsest, or siltiest, (clay:mud ratio < 0.50) in two areas -- one adjacent to the southeast wall of the dike between spillways #3 and #4 and the other just offshore of Miller Island (station MDE-32). Beyond those two areas, the muddy fraction of sediments deposited around the dike is clay-rich. Clay:mud ratios are highest (>0.60) in a lens of sediments east of spillway #4 and in two other pockets – MDE-33, northeast of spillway #2, and MDE-26, the southernmost station.

In April 1999, the distribution of the clay:mud ratio changed somewhat. The band of silt-rich sediments southeast of the dike persisted through the spring. However, the area contracted

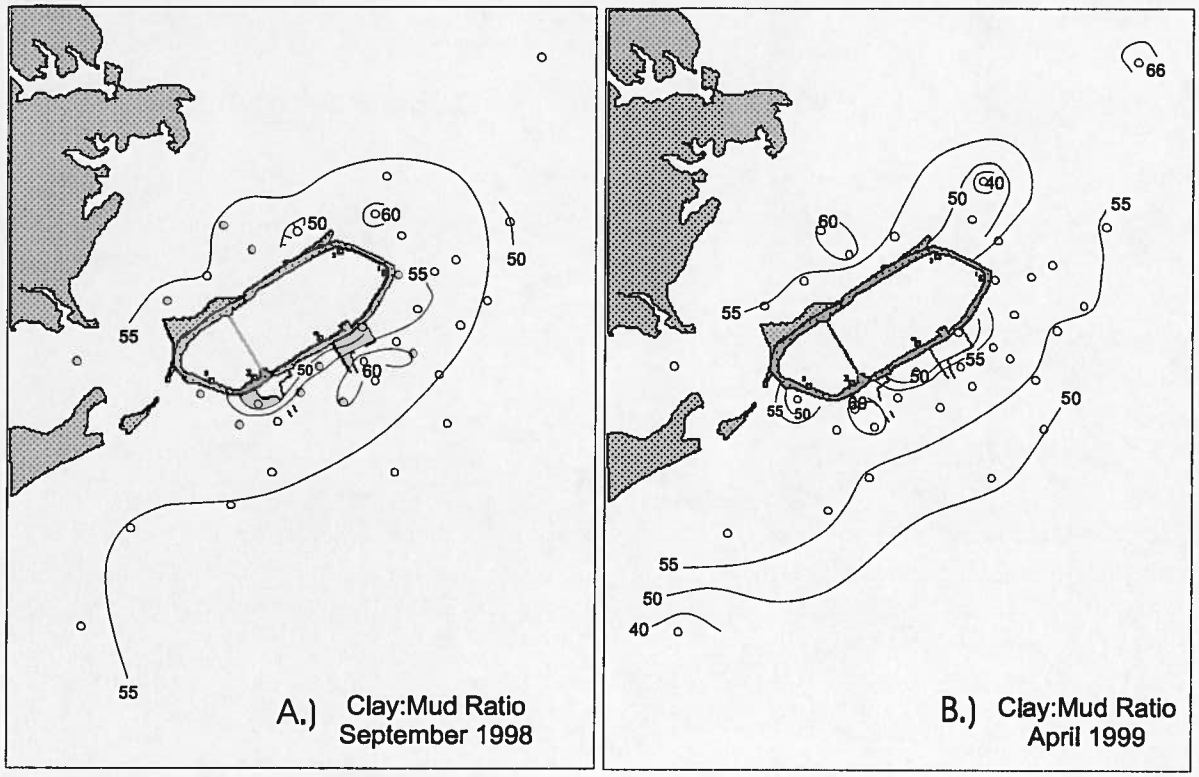

Figure 2-8: Clay:Mud Ratios for Year 17.

slightly in size. The fine fraction of sediments adjacent to spillway #3 (MDE-19) was silt-rich in the fall and clay-rich the following spring. The same coarse-to-fine pattern was also evident at MDE-32, northwest of Miller Island. The opposite trend -- coarsening of the fine fraction -- was apparent in the area north of the dike. In September 1998, sediments there were decidedly rich in clay; by spring, sediments were considerably siltier.

Clay-rich areas (>0.50) persisted through the spring, though the highest ratios (>0.60) shifted. On the southeast side of the dike, the highest ratios shifted southwestward, to an area adjacent to spillway #3. Likewise, ratios were slightly higher in Hawk Cove in the spring, compared to the fall.

For a few stations, station-by-station comparisons of sand content and of clay:mud ratios revealed differences over the course of the year. Sand content increased markedly (by 15 percentage points or more) at two stations (MDE-24 and MDE-29) and decreased at three others (MDE-7, MDE-16, and MDE-31). The fine fraction of sediments collected at stations MDE-19 and MDE-20, became more clay rich between September 1998 and April 1999. At the same time, the fine fraction of the sediment became coarser (siltier) at stations MDE-16, MDE-24, MDE-33, and MDE-35. Further from the dike, the clay:mud ratio also changed at two reference stations. At MDE-26, located at the southern limit of the study area, the fine fraction became siltier. In contrast, the muddy fraction of MDE-36, at the northern limit, became finer (richer in clay).

Understanding the reasons for these variations in grain size distribution is difficult. They involve the amount, quality, and timing of discharge from particular spillways and the interaction of the effluent with tides and currents in the receiving waters. Those, in turn, are influenced by flow from the Susquehanna River. Alternatively, sediment composition in these areas may vary locally. In that case, if the research vessel occupies a slightly different position from one cruise to the next, grain size will vary solely as a function of boat location. Whatever the cause of the variation, no clear trends, affecting many samples from a large area, are evident. The grain size distribution of Year 17 sediment samples is consistent with the findings of previous monitoring years.

Elemental Analyses

Nutrients: Carbon, Nitrogen, and Phosphorus

There is a concern that HMI is a source of nutrients to the upper Bay. As a result, it would be expected that any particulate matter enriched in nutrients and that are discharged from the facility may influence the external sedimentary environment, as has been seen in previous years in relation to metals loading. Table 2-5 lists the gross statistics for the concentrations of total C, N, and P found in the sediments surrounding HMI. These values are in the concentration ranges of these elements found in the northern Bay. In order to assess whether there is any enrichment due to localized sources such as HMI, it must be first determined if there is any enrichment and secondly does the distribution pattern of the enrichment suggest a localized source. Table 2-3 is a list of the ratios of the three nutrients to one another measured from this study; the Redfield ratio (Redfield et al. 1966) is given for comparison. Redfield's ratio is the ratio of nutrients found in plankton (C:N:P = 106:16:1); it is commonly used as a reference to gauge diagenetic reactions, and the input of organic material from of different sources.

Table 2-3: Nutrient ratios found in the study area for Year 17 as compared to Redfield's ratio.

	N/C	P/C	P/N
Redfield's	0.176	0.024	0.138
HMI (this study)	0.068	0.027	0.412
Standard Dev.	0.013	0.006	0.067
Relative Stand. Dev.(RSD)	19%	22%	16%

Within the northern Bay the two sources of carbon are plankton and terrigenous material (Hennessee et al. 1986; Cornwell et al. 1994). The plankton behave in accord with Redfield's ratio while the terrigenous (non-reactive) carbon, derived from coal and plant litter, is virtually

devoid of N and P. The N/C ratio indicates that carbon is enriched 2.6 times above what would be expected, through the addition of non-reactive carbon. Based on the P/N ratio, P is enriched by a factor of three over the amount predicted by Redfield's ratio; this enrichment is identical to what would be found if the carbon is adjusted in the P/C to reflect the 2.6 enrichment. These enrichments are typical of what is found in the northern Bay (Hennessee et al. 1986, Cornwell et al. 1994, Berner 1981). In addition, when the data are plotted on a map of the area, the distributions show a relatively uniform pattern, as would be expected from the low RSD. Discharge from HMI does not leave a C, N or P signature in the exterior sediments. This does not mean that there are no significant discharges of nutrients into the Bay from HMI, only that the nutrients discharged are in a dissolved or suspended phase that does not settle quickly in the area adjacent to the facility.

Trace Metals

Interpretive Technique

Eight trace metals were analyzed as part of the ongoing effort to assess the effects of operation of the containment facility on the surrounding sedimentary environment. The method used to interpret changes in the observed metal concentrations takes into account grain size induced variability and references the data to a regional norm. The method involves correlating trace metal levels with grain size composition on a data set that can be used as a reference for comparison. For the HMI study area, data collected between 1983 and 1988 are used as the reference. Samples collected during this time showed no aberrant behavior in trace metal levels. Normalization of grain size induced variability of trace element concentrations was accomplished by fitting the data to the following equation:

$$X = a(\text{Sand}) + b(\text{Silt}) + c(\text{Clay}) \qquad (2)$$

where X = the element of interest
a, b, and c = the determined coefficients
Sand, Silt, and Clay = the grain size fractions of the sample

A least squares fit of the data was obtained by using a Marquardt (1963) type algorithm. The results of this analysis are presented in Table 2-4. The correlations are excellent for Cr, Fe, Ni, and Zn, indicating that the concentrations of these metals are directly related to the grain size of the sediment. The correlations for Mn and Cu are weaker, though still strong. In addition to being part of the lattice and adsorbed structure of the mineral grains, Mn occurs as oxy-hydroxide chemical precipitate coatings. These coatings cover exposed surfaces, that is, they cover individual particles as well as particle aggregates. Consequently, the correlation between Mn and the disaggregated sediment size fraction is weaker than for elements, like Fe, that occur primarily as components of the mineral structure. The behavior of Cu is more strongly influenced by sorption into the oxy-hydroxide than are the other elements. The poor relationship with regard to Cd is due to the baseline being established at or near the detection limit. Baseline levels for Cd and Pb were determined from analyses of 30 samples collected in a reference area on the eastern

side of the Northern Bay. The baseline was established as part of a study examining toxic loading to Baltimore Harbor.

Table 2-4: Coefficients and R^2 for a best fit of trace metal data as a linear function of sediment grain size around HMI. The data are based on analyses of samples collected during eight cruises, from May 1985 to April 1988.

$$X = [\ a*Sand + b*Silt + c*Clay\ ]/100$$

	Cr	Mn	Fe	Ni	Cu	Zn	Pb	Cd
a	25.27	668	0.553	15.3	12.3	44.4	6.81	0.32
b	71.92	218	1.17	0	18.7	0	4.10	0.14
c	160.8	4158	7.57	136	70.8	472	77	1.373
R^2	0.733	0.36	0.91	0.82	0.61	0.77	0.88	0.12

The strong correlation between the metals and the physical size fractions makes it possible to predict metal levels at a given site if the grain size composition is known. This can be done by substituting the least squares coefficients from Table 2-4 for the determined coefficients in equation 2. These predicted values can then be used to determine variations from the regional norm due to deposition; to exposure of older, more metal-depleted sediments; or to loadings from anthropogenic or other enriched sources.

The following equation was used to examine the variation from the norm around HMI.

$$\%\ \text{excess Zn} = \frac{(\text{measured Zn} - \text{predicted Zn})}{\text{predicted Zn}} * 100 \quad (3)$$

Zn is used in the following discussion as an indicator of change in sediment chemistry. As elaborated in previous reports (Kerhin et al. 1982a, Wells et al. 1984), there are several reasons for focusing on Zn:

1. Of the chemical species measured, Zn has been the least influenced by variation in analytical technique. Since 1976, at least four different laboratories have been involved in monitoring the region around HMI. The most consistent results have been obtained for Zn;

2. Zn is one of the few metals in the Bay that has been shown to be affected by anthropogenic input;

3. There is a significant down-Bay gradient in Zn enrichment that can be used to detect the source of imported material; and

4. Zn concentrations are highly correlated with other metals of environmental interest.

In Equation 3, the differences between the measured and predicted levels of Zn are normalized to predicted Zn levels. This means that, compared to the regional baseline, a value of zero (0%) excess metal is at the regional norm, positive values are enriched, and negative values are depleted. Direct comparisons of different metals in all sediment types can be made due to the method of normalization. As useful as the % Excess Metal values are, alone they do not give a complete picture of the loading to the sediments - natural variability in the samples as well as analytical variations must be taken into account. As result of the normalization of the data, Gaussian statistics can be applied to the interpretation of the data. Data falling within ±2 (±2 standard deviations) are within normal background variability for the region. Samples with a value of ±3 can be within accepted background variability, but it is marginal depending on the trends in the distribution. Any values falling outside this range indicate a significant perturbation to the environment. The standard deviation of the baseline data set, the data used to determine the coefficients in Equation 2, is the basis for determining the sigma level of the data. Each metal has a different standard deviation, as reflected in the R^2 values in Table 2-4. The sigma level for Zn is ~30% (e.g. 1 = 30%, 2 = 60%, etc.)

General Results

A listing of the summary statistics for the elements analyzed is given in Table 2-5. Some features to note are:

1. Most of the samples (56 of 71) are below the detection level for Cd (0.10);
2. Cr, Cu, Ni, Pb and Zn are found with concentrations that exceed the Effects Range Low (ERL) values; and
3. Zn and Ni exceed the Effects Range Median (ERM) values.

ERL and ERM are proposed criteria put forward by National Oceanic and Atmospheric Administration (NOAA - Long et al. 1995) to gauge the potential for deleterious biological effects from contaminated sediments. Sediments with concentrations below the ERL are considered baseline concentrations with no expected adverse effects. Concentrations between the ERL and ERM may have adverse impacts to benthic organisms, while values greater than the ERM have probable adverse biological effects. These criteria are based on a statistical method of termed preponderance of evidence. The method does not allow for unique basin conditions and does not take into account grain size induced variability in metal concentrations in the sediment. The values are useful as a guide, but are limited in applicability due to regional difference. The grain size normalization procedure outlined in the previous section is a means to correct the deficiencies of the guidelines by taking into account the unique character of Chesapeake Bay sediments and eliminating grain size variability. When the data are normalized, only Zn and Pb

are found to be significantly enriched compared to the baseline; however, based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Table 2-5: Summary statistics for elements analyzed.

[All concentrations are in μg/g unless otherwise noted]

Summary Statistics

	Cd	*Cr*	*Cu*	*Fe(%)*	*Mn*	*Ni*	*Pb*	*Zn*
Count	15	71	71	71	71	71	71	71
Average	0.235	101	41.9	3.90	2681	69.3	49.1	290
Standard deviation	0.105	39.7	23.6	1.52	1413	31.1	24.4	130
Minimum	0.1	8.79	4.0	0.33	412	5.29	0.037	30
Maximum	0.43	169	174	5.88	7319	145	105	583
Range	0.33	160	170	5.55	6907	140	105	553
ERL	1.3	81	34	N/A	N/A	20.9	46.7	150
# of Samples >ERL	(0)	(54)	(50)			(66)	(43)	(57)
ERM	9.5	370	270	N/A	N/A	51.6	218	410
# of Samples >ERM	(0)	(0)	(0)			(52)	(0)	(11)

	Carbon (%)	*Nitrogen (%)*	*Phosphorus*
Count	71	71	71
Average	3.08	0.206	822
Standard deviation	1.15	0.0807	308
Minimum	0.414	0.0202	129
Maximum	5.12	0.464	1392
Range	4.71	0.444	1263

Metal Loadings

Since the eighth monitoring year, increased levels of Zn have been noted in bottom sediments east and south of spillway #1. The results of previous monitoring studies have shown that the areal extent and magnitude of metals loadings to the exterior sedimentary environment is controlled by three primary factors. These factors are:

1. Discharge rate - controls the amount of metals discharged to the external sedimentary environment. Discharge from HMI at flows less than 10 MGD contribute excess metals to the sediment (see *Twelfth Year Interpretive Report*). The high metal loading to the exterior environment is the result of low input of water, which allows exposure of the sediment to the atmosphere. When the sediments are exposed to atmospheric oxygen, naturally occurring sulfide minerals in the sediment oxidize to produce sulfuric acid, which leaches metals and other acid-soluble chemical species from the sediment. The process is similar to acid mine drainage. At discharge rates greater than 10 MGD, the water throughput (input from dredge disposal to release of excess water) submerges the sediment within the dike, minimizing atmospheric exposure, and dilutes and buffers any acidic leachate. As a result, higher discharge rates produce metal loadings that are close to background levels.

2. Flow of freshwater into the Bay from the Susquehanna River - The hydrodynamics of the Bay in the area of HMI are controlled by the mixing of freshwater and brackish water south of the area. Details of the hydrodynamics of this region were determined by a modeling effort presented as an addendum to the *10th Year Interpretive Report* (Wang, 1993). The effects of Susquehanna flow to the contaminant distribution around HMI follow;
   a. A circulation gyre exists east of HMI. The gyre circulates water in a clockwise pattern, compressing the discharge from the facility against the eastern and southeastern perimeter of the dike;
   b. The circulation gyre is modulated by fresh water flow from the Susquehanna River. The higher the flow from the Susquehanna, the stronger the circulation pattern and the greater the compression against the dike. Conversely, the lower the flow, the less the compression and the greater the dispersion away from the dike; and
   c. Discharge from the dike has no influence on the circulation gyre. This was determined by simulating point discharges of 0-70 MGD from three different spillways. Changes in discharge rate only modulated the concentration of a hypothetical conservative species released from the dike; the higher the discharge, the higher the concentration in the plume outside the dike.

3. The positions of the primary discharge points from the dike - The areal distribution of the metals in the sediment also depends on the primary discharge locations to the Bay. The effects of discharge location were determined as part of the hydrodynamic model of the region around HMI. The effects of discharge location are:
   a. Releases from spillways #1 and #4 travel in a narrow, highly concentrated band up and down the eastern side of the dike. This explains the location of the areas of periodic high metal enrichment to the east and southeast of the facility; and
   b. Releases from spillway #2 are spread more evenly to the north, east, and west. However, dispersion is not as great as from spillways #1 and #4 because of the lower shearing and straining motions which occur away from the influence of the gyre.

The 3-D hydrodynamic model explains the structure of the plume of material found in the exterior sediments, and the functional relationship of contaminants to discharge rate accounts for the magnitude of the loading to the sediments.

Figure 2-9 shows the sigma levels for Zn in the study area adjacent to HMI for Fall 1998 and Spring 1999. Sigma levels are the multiple of the standard deviation of the baseline data set. Data that falls within +/-2 sigma are considered within normal baseline variability. Data within the 2 -3 sigma range are transitional; statistically one sample in 100 would normally be expected to occur, in a small data set. The occurrence of 2 or more spatially contiguous stations in this range is significant. Any sample >3 sigma is significantly elevated above background. Figure 2-9 Shows only the significantly elevated stations. The zone in which the exterior sediments have been consistently elevated with Zn, due to the operations of the dike are outlined in Figure 2-1; the zone closest to the eastern side of the dike has been the most significantly influenced. For Year 17, the levels of metal elevation in the area influenced by HMI are some of the lowest since elevated levels were first noted in 1989. All but three stations for both cruises were within the levels considered normal baseline concentrations. Two sites which are attributable to HMI are slightly elevated and the southernmost station, which may be influenced by proximity to Baltimore Harbor, is also elevated. The minimal influence of HMI can be attributed to facility operations. The low levels are put into historical

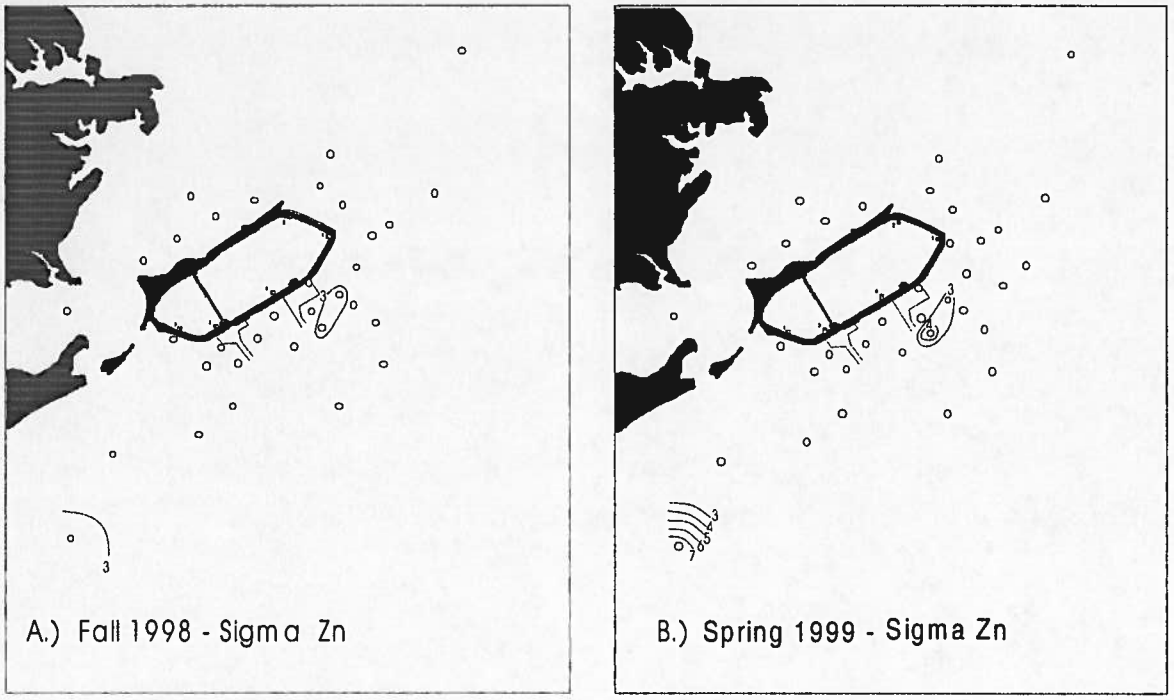

Figure 2-9: Sigma level values for the two Year 17 cruises.

perspective in Figure 2-10. This figure shows the maximum % excess Zn found within the zone historically influenced by HMI for each of the monitoring cruises. The last two points represent the maxima found during the cruises for Year 17. The Fall cruise shows the lowest value of % Excess Zn since the onset of the elevated levels in 1989, and the Spring cruise levels are only slightly elevated from the Fall. Although there were significant periods during which discharge rates were below 10

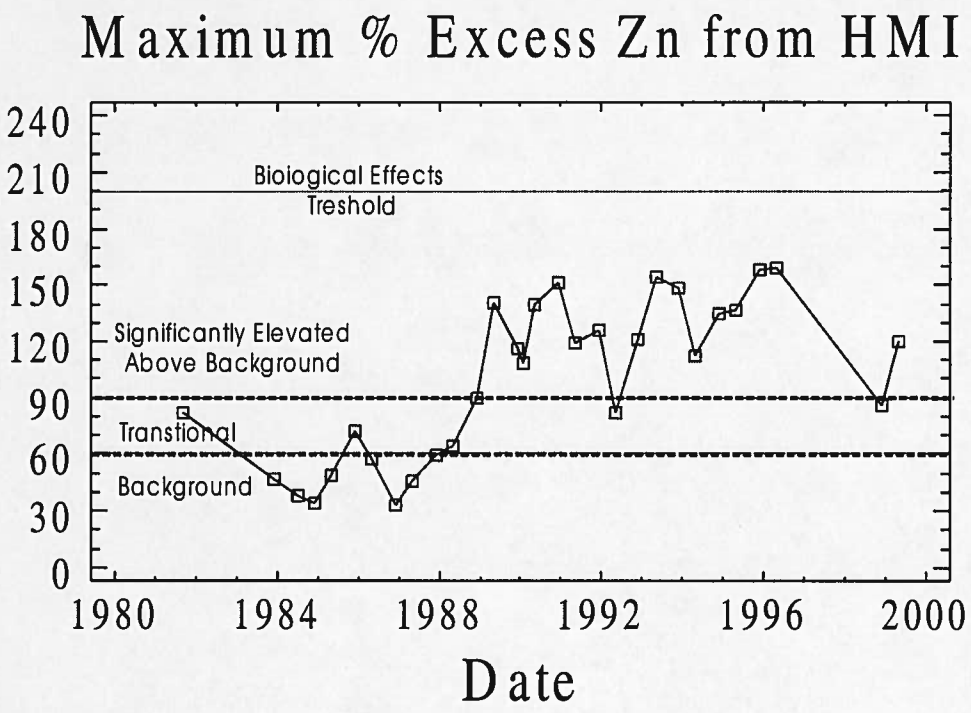

Figure 2-10: Record of the maximum % Excess Zn for all of the cruises MGS analyzed the sediments.

MGD; the most acidic daily discharge records did not show periods of free mineral acidity (see Figure 2-3). Without the free mineral acidity, leaching is minimized and acid formation rates are relatively low. This accounts for the low observed levels of Zn in the exterior sediments.

Lead was also significantly elevated above baseline levels. The distribution patterns for Pb follow the distribution of Zn elevation; a signature from HMI and elevated levels to the south probably due to the influence of Baltimore Harbor. Additionally, there is a elevation of Pb in the Hawk Cove area related to Back River. The elevated levels of Pb are well below thresholds where adverse biological effects would be expected (Long et al. 1995, Hill in prep.), similar to the Zn levels.

CONCLUSIONS AND RECOMMENDATIONS

The grain size distribution of Year 17 sediment samples does not show any clear trends between cruises. This is due to the complexity of the environmental conditions and source of material to the area. However, the general sediment distribution pattern is consistent with the findings of previous monitoring years dating back to 1988 (the second year after the start of effluent release from HMI).

Discharge from HMI apparently does not leave a C, N or P signature in the exterior sediments. This is based on the use of Redfield's Ratio, data from the mainstem Bay and the distribution pattern of these elements around the facility. However, this does not mean that significant discharge of nutrients into the upper Bay from HMI are not occurring. Nutrients discharged in a dissolved or suspended phase, which do not settle quickly in the area adjacent to the facility, would not be detected in exterior monitoring of the sediment.

For Year 17, the levels of metal elevation in the area influenced by the dike are some of the lowest since the elevated levels were first noted in 1989, and the Spring cruise levels are only slightly elevated from the Fall. All but three stations for both cruises were within the levels considered normal baseline concentrations. Two sites which are attributable to HMI are slightly elevated and the southernmost station, which may be influenced by proximity to Baltimore Harbor, was also elevated. The minimal influence of HMI can be attributed to facility operations. Although there were significant periods where the discharge rates dropped below 10 MGD, acidic conditions did not form. Consequently, leaching of the sediment was minimized and the rate of acid formation was greatly reduced.

Chromium, Cu, Ni, Pb and Zn were found with concentrations that exceed the ERL values, and Zn and Ni exceeded the ERM values. However, when the data was normalized only Zn and Pb were found to be significantly enriched compared to the baseline. Based on work done in Baltimore Harbor, the normalized values are well below anticipated biological effects thresholds.

Persistent elevated metal levels in sediments around HMI indicate a need for continued monitoring. Even though HMI has nearly reached its capacity and the volume of effluent is expected to decline, dewatering of the confined material may lead to higher metal levels in the effluent. Exposure of dredged material to the atmosphere is likely to result in the mobilization of metals associated with those sediments, an effect analogous to acid mine drainage. Metals released in the effluent, particularly at low discharge rates, are deposited on the surrounding Bay floor and are increasing the long term metal loading to the Bay. Although the enriched levels of these metals are much lower than any biological effects threshold, continued monitoring is needed to detect if the levels increase to a point where action is required. In addition, monitoring is required to assess the effectiveness of any amelioration protocol implemented by MES to counteract the effects of exposing dredged material to the atmosphere. Close cooperation with MES will be important in this endeavor.

It is further recommended, in order to assess the influence of Baltimore Harbor on the HMI exterior sediments, that additional sampling sites be added to the south of the facility. Sites in the southern portion of the study area have consistently shown elevation in metal levels through virtually

all of the sampling cruises. It has been postulated that the elevated levels are from Baltimore Harbor, but no spatially contiguous record exists which links these two areas. Additional sites would provide adequate spatial coverage to measure any gradient from the Harbor to HMI.

CHAPTER III: BENTHIC COMMUNITY ASSESSMENT (Project 3)
MONITORING YEAR 17 (September 1998 – April 2000)

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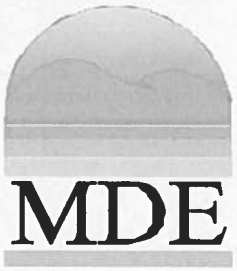

ACKNOWLEDGMENTS

Staff from the Maryland Department of the Environment's Field Office Program was instrumental in completing the field work for this project. We would like to thank Mr. William Evans, Jr., Mr. Jonathan Stewart, Mr. Dennis Rasmussen, and Mr. Gilbert Lookingland of the Field Office Program for their assistance with collection of the macroinvertebrate and sediment samples.

Special thanks are due to Mr. Chad Barbour and Ms. Lisa Matarazzo who assisted with the laboratory processing of the sediment and benthic macroinvertebrate samples.

Thanks are also due to Mr. Matthew Rowe who assisted by putting together the tables used in this report and by commenting on the draft technical and data reports. Mr. Nathaniel Brown provided assistance by tracking the budget and provided other assistance as needed throughout the study. Mr. Visty Dalal served as project manager. Mr. Michael Haire and Dr. Robert Summers served as the former and present Directors of TARSA, respectively, during this project.

ABSTRACT

The benthic macroinvertebrate community in the vicinity of the Hart-Miller Island Dredged Material Containment Facility (HMI) was studied for the seventeenth year as Project III of the HMI Exterior Monitoring Program. Communities living at stations close to the facility (nearfield stations) were compared to communities sampled beyond the influence of HMI (reference stations). Communities living at the mouth of Back River and in Hawk Cove were also examined.

Seventeen stations were sampled on September 23, 1998, and again on May 10-11, 1999. Among these were 11 nearfield stations (MDE-1, MDE-3, MDE-7, MDE-9, MDE-16, MDE-17, MDE-19, MDE-24, MDE-33, MDE-34, MDE-35), 3 reference stations (MDE-13, MDE-22, MDE-36), and 3 Back River/Hawk Cove stations (MDE-27, MDE-29, MDE-30). Infaunal samples were collected using a Ponar grab sampler, which collects 0.05 m^2 of substrate. Water quality parameters, including dissolved oxygen concentrations, salinity, temperature, conductivity and pH were measured *in situ*. Water quality parameters were measured using a Hydrolab Surveyor II or Yellow Springs Instruments (YSI) multi-parameter water quality meter at intervals from the bottom of the water column. Secchi depth was also measured at each station.

A total of 32 benthic macroinvertebrate taxa were found at these seventeen benthic community stations. Of these 32 taxa, five taxa (the clam *Rangia cuneata*, the polychaete worms *Streblospio benedicti* and *Neanthes succinea*, oligochaete worms in the family Tubificidae, and the isopod crustacean *Cyathura polita*) were numerically dominant during both seasons. Total abundance was higher at most stations in the spring than late summer due to high seasonal recruitment, especially of the polychaete worm *Marenzelleria viridis* and the amphipod crustacean *Leptocheirus plumulosus*.

Diversity was examined using the Shannon-Wiener diversity index. Diversity ranged from 1.06 to 2.63 in late summer and from 1.39 to 3.05 in the spring. Diversity was greatly influenced by the abundance of a few taxa; particularly the clam *Rangia cuneata*, the polychaete worm *Marenzelleria viridis*, and the amphipod *Leptocheirus plumulosus*. Together these species accounted for over 50% of the individuals at each station in the spring. Diversity increased in spring at some stations, particularly the Back River/Hawk Cove stations, as additional species were encountered.

The proportion of pollution-sensitive taxa (*Macoma balthica, Cyathura polita, Rangia cuneata*, and *Marenzelleria viridis*) was generally higher in May 1999 than in September 1998. This was primarily due to spring recruitment of *M. viridis*. The proportion of pollution-indicative taxa (the polychaete worms *Eteone heteropoda* and *Streblospio benedicti*, oligochaete worms in the family Tubificidae, and midge larvae [family Chironomidae]) was higher at all stations in September than in May. This was due to the large numbers of *S. benedicti* found in September and seasonal decreases in the number of *M. viridis*.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI; Weisberg et al. 1997) was calculated for all stations based on the September data only. Fifteen benthic stations, including all three reference stations, met or exceeded the Restoration Goal of a B-IBI score of 3.0. Only

two stations, nearfield station MDE-19 and Back River station MDE-27, failed to meet the restoration goal. MDE-19 lies in an area that has historically been associated with disturbance of the substrate by barge traffic serving HMI. MDE-27 lies at the mouth of the Back River and is likely influenced by water quality in the Back River.

INTRODUCTION

In order to keep the economically important shipping lanes in Baltimore Harbor and its approaches open, periodic dredging – and subsequent placement of dredged material – must occur. The Hart-Miller Island Dredged Material Containment Facility (HMI) was originally designed to receive contaminated material from the Inner Harbor, as well as other polluted sites. HMI also served as the disposal site for 5.3 million cubic yards of dredged material collected when shipping channels were deepened to fifty feet (MDNR 1985). The facility is located in the upper region of Chesapeake Bay, near the mouth of Back River. The dike was constructed between 1981 and 1983 and connects Hart and Miller Islands. The area inside the dike encompasses approximately 1,100 acres. Placement of dredged material began after completion of the dike in 1983, and continues today (MDE 1999a).

Various agencies have worked together since the beginning of this project to monitor for environmental impacts resulting from dike construction and dredged material placement activities. Early studies of benthic biota were conducted in the vicinity of Hart and Miller Islands in 1972-1978, prior to any disturbance of the area by dredging-related activities (Allison and Butler 1981). This report represents the seventeenth year of the benthic macroinvertebrate community monitoring since the inception of the Hart Miller Island Exterior Monitoring Program in 1981. In Year 17, the Maryland Department of the Environment was responsible for all aspects of benthic community monitoring.

The goals of the Year 17 benthic community monitoring project were:

- To monitor the benthic community condition in order to fulfill compliance monitoring requirements related to water quality;
- To examine the condition of the benthic macroinvertebrate community using, among other analytical tools, the Chesapeake Bay Benthic Index of Biological Integrity (B-IBI) (Weisberg et al. 1997), and to compare the results to present local reference conditions; and
- To facilitate trend analysis by providing data of high quality and comparing the results with those of past studies of the waters around HMI.

METHODS AND MATERIALS

For the Year 17 benthic community studies, staff from the Maryland Department of the Environment's Biological Assessment Section and Field Office Program collected benthic macroinvertebrate samples and measured several *in situ* water quality parameters on September 23, 1998, and on May 10 and 11, 1999. Seventeen benthic stations (Figure 3-1; Table 3-1) in the

vicinity of the Hart-Miller Island Dredged Material Containment Facility were included in the study. All benthic community sampling stations coincided with stations sampled by the Maryland Geological Survey (MGS) for sedimentary analysis. Stations were located using a Differential Global Positioning System (GPS) navigation unit.

Table 3-1: Locations (latitudes and longitudes in degrees, decimal minutes), major sediment type, and 7-digit codes of stations sampled during Year 17 benthic community monitoring.

Station #	Latitude	Longitude	Sediment Type	Maryland 7-Digit Station Designation
Nearfield Stations				
MDE-01	39° 15.3948	76° 20.568	Shell	XIF5505
MDE-03	39° 15.5436	76° 19.9026	Sand	XIG5699
MDE-07	39° 15.0618	76° 20.3406	Silt/clay	XIF5302
MDE-09	39° 14.7618	76° 20.5842	Silt/clay	XIF4806
MDE-16	39° 14.5368	76° 21.4494	Silt/clay	XIF4615
MDE-17	39° 14.1690	76° 21.1860	Silt/clay	XIF4285
MDE-19	39° 14.1732	76° 22.1508	Silt/clay	XIF4221
MDE-24	39° 14.2650	76° 22.7862	Sand	XIF4372
MDE-33	39° 15.9702	76° 20.8374	Sand	XIF6008
MDE-34	39° 15.7650	76° 20.5392	Sand	XIF5805
MDE-35	39° 16.3182	76° 20.7024	Silt/clay	XIF6407
Reference Stations				
MDE-13	39° 13.5102	76° 20.6028	Shell	XIG3506
MDE-22	39° 13.1934	76° 22.4658	Silt/clay	XIF3224
MDE-36	39° 17.4768	76° 18.9480	Silt/clay	XIG7589
Back River/Hawk Cove Stations				
MDE-27	39° 14.5770	76° 24.2112	Silt/clay	XIF4642
MDE-29	39° 15.3900	76° 22.7304	Silt/clay	XIF5427
MDE-30	39° 15.8502	76° 22.5528	Silt/clay	XIF5925

Temperature, depth, salinity, pH, conductivity, and dissolved oxygen were measured *in situ* using a Hydrolab Surveyor II water quality meter in September 1998. In May 1999, a Yellow Springs Instruments (YSI) water quality meter was used to measure *in situ* temperature, depth, salinity, pH, conductivity, dissolved oxygen, and turbidity. Water quality parameters were measured at approximately 0.5 m (1.6 feet) from the surface, 1.0 m (3.3 feet) from the bottom, and at one meter intervals from the bottom to develop a vertical water quality profile at each station. Secchi depth was measured at all stations during both seasons. Data from all depths are found under Project III in the *Year 17 Data Report*.

Semi-quantitative benthic samples were collected using a Ponar grab sampler, which collects approximately 0.05 m^2 (0.56 ft^2) of bottom substrate. Three replicate benthic grab samples were collected from each station. Samples were rinsed through a 0.5-mm sieve on board the vessel and preserved in a solution of 10% formalin and bay water, including rose Bengal biological stain to assist in laboratory recognition of specimens.

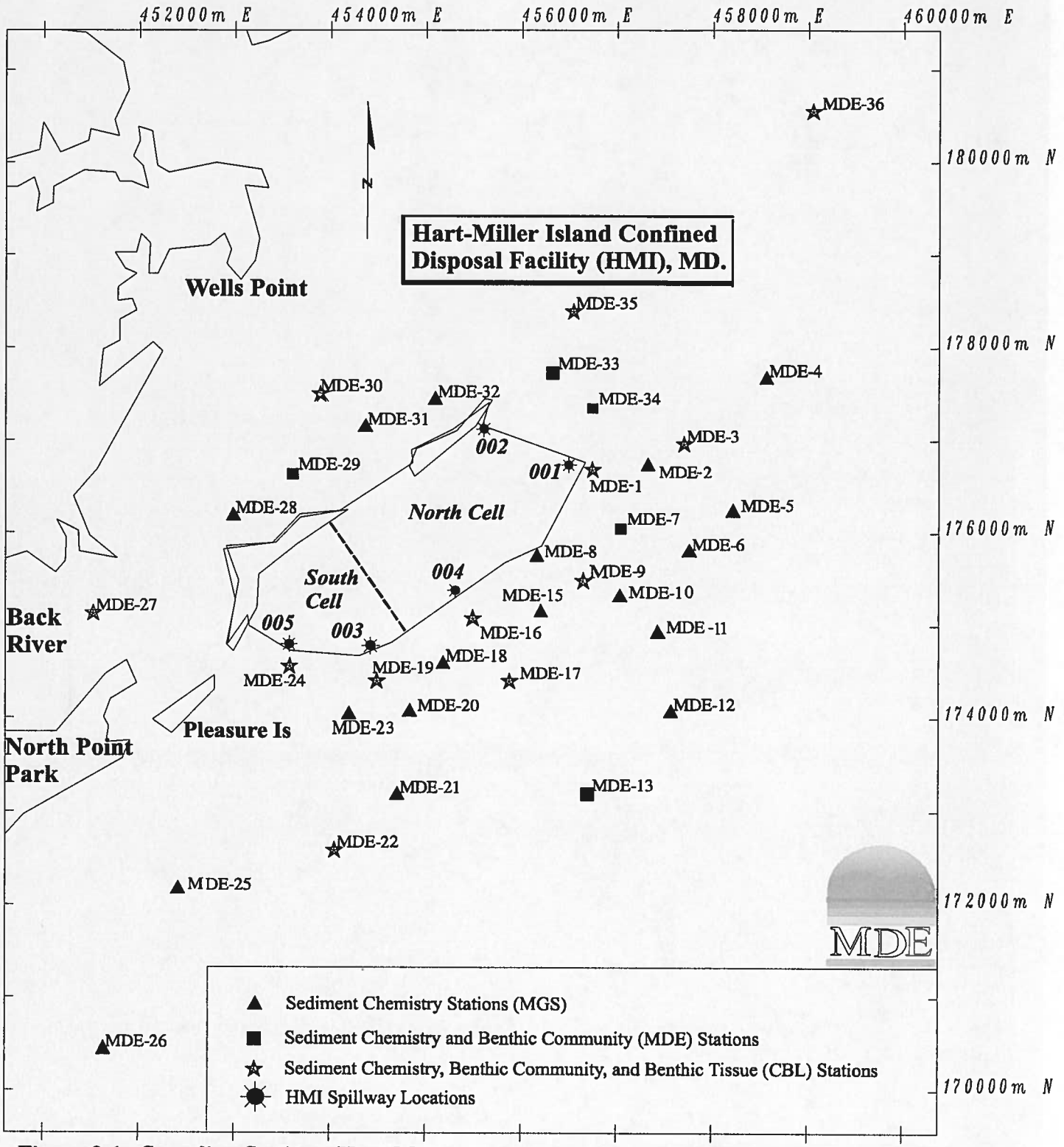

Figure 3-1: Sampling Stations, Hart-Miller Island Exterior Monitoring Study, Year 17. Project II (sediment chemistry) conducted by Maryland Geological Survey (MGS). Project III (benthic community studies) conducted by Maryland Department of the Environment (MDE). Project IV (sediment & benthic tissue toxicity) conducted by University of Maryland Chesapeake Biological Laboratory (CBL).

In the laboratory, each benthic macroinvertebrate sample was placed into a 0.5-mm sieve and rinsed to remove the field preservative. Organisms were sorted from debris, separated into vials by major taxonomic groups, and preserved in 70% ethanol. Large organisms were identified to the lowest practical taxon using a stereo dissecting microscope. Members of the insect family Chironomidae were mounted on slides and identified to genus, when possible, using a binocular compound microscope. Individuals of the most common clam species (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*) were measured to the nearest millimeter. All identifiable organisms were enumerated.

Subjective estimates (nearest 5%) of the percent contributions of detritus, gravel, shell, sand, and silt/clay (mud) to the sediment were made in the field. In addition, approximately 200 to 400 grams of sediment were taken from a fourth grab sample collected at each station. These sediment samples were taken to the laboratory, where a representative subsample of each was used to determine water content and grain size distribution. These sediment subsamples were weighed, wet sieved and dried in an oven according to MDE's Standard Operating Procedures for sediment analysis (MDE 1999b). Total dry weight was determined by summing the weights of the various size fractions. Each fraction was expressed as a percentage of the total dry weight. Water content was expressed as a percentage of the wet sediment weight.

Six main measures of benthic community condition were examined, including: total infaunal abundance, relative abundance of pollution-indicative infaunal taxa, relative abundance of pollution-sensitive infaunal taxa, the Shannon-Wiener diversity index, taxa richness and total abundance of all taxa (excluding Bryozoa). The first four of these measures were used to calculate the Chesapeake Bay B-IBI (Weisberg et al. 1997) for September 1998. The B-IBI has not been calibrated for periods outside the summer index period (July 15 through September 30). We also examined the numerically dominant taxa during each season and length frequency distributions of the three most common clams (*Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli*).

Abundance measures were calculated based on the average abundance of each taxon in the three replicate samples at each station. Total Abundance was calculated as the total number of organisms per square meter (m^2), excluding colonial Bryozoa. Total Infaunal Abundance was calculated as the total number of infaunal organisms per square meter. Taxa that were designated as "epifaunal" for the calculation of the B-IBI (see Ranasinghe et al. 1994) were excluded from the total infaunal abundance. The taxa excluded as epifaunal were snails in the family Hydrobiidae, the mussel *Mytilopsis leucophaeata*, the amphipods *Apocorophium lacustre* and *Melita nitida*, the crab *Rhithropanopeus harrisii*, the barnacle *Balanus improvisus*, and the isopod *Edotea triloba*. Members of the phylum Bryozoa (bryozoans) were excluded because they are not only epifaunal, but also colonial. Estimates of the number of live bryozoan zooids are included in the *Year 17 Data Report*.

Pollution-Sensitive Taxa Abundance was calculated as the percentage of total infaunal abundance represented by pollution-sensitive taxa (the clams *Macoma balthica* and *Rangia cuneata,* the worm *Marenzelleria viridis,* and the isopod *Cyathura polita*). Pollution-Indicative Taxa Abundance was calculated as the percentage of total infaunal abundance represented by pollution-indicative taxa (the midges *Coelotanypus* sp. and *Procladius* sp., and the polychaete worms *Streblospio benedicti* and *Eteone heteropoda*). Taxa were designated as pollution-

indicative or pollution-sensitive according to Weisberg et al. (1997). Because all identifiable midges were *Coelotanypus* or *Procladius*, all midges were included as pollution-indicative. The Shannon-Wiener Diversity Index (H') was estimated using the machine formula provided in Weber (1973). Taxa richness (number of taxa) was calculated for each station as the total number of taxa found in all three replicates. Infaunal taxa richness was calculated as the number of infaunal taxa found in all three replicates. The abundance of the three most common taxa at reference and monitoring stations was also examined. This measure included epifaunal taxa other than bryozoans.

The scientific names of several organisms collected over the years as part of the Hart-Miller Island Exterior Monitoring Program have changed. Table 3-2 lists the old and new names of these organisms. It also lists common names of these and other organisms that have been found routinely at HMI.

Table 3-2: Synonyms and common names of organisms routinely found in the sediments around Hart-Miller Island Dredged Material Containment Facility. The list includes only those organisms whose scientific names have changed since the beginning of the HMI Exterior Monitoring Program in 1981, or for which common names are available.

Old Name	New Name	Common Name
Nereis succinea	*Neanthes succinea*	Clam worm
Polydora ligni	*Polydora cornuta*	Whip mud worm
Scolecolepides viridis	*Marenzelleria viridis*	Red-gilled mud worm
Congeria leucophaeta	*Mytilopsis leucophaeata*	Dark falsemussel
Macoma balthica		Baltic macoma clam
Macoma mitchelli		Mitchell's macoma clam
Rangia cuneata		Brackish water clam
Balanus improvisus		Bay barnacle
Cyathura polita		Slender isopod
Edotea triloba		Mounded-back isopod
Leptocheirus plumulosus		Common burrower amphipod
Corophium lacustre	*Apocorophium lacustre*	Slender tube-builder amphipod
Gammarus species		scuds
Monoculodes edwardsi	*Ameroculodes spp. complex*	Red-eyed amphipod
Rhithropanopeus harrisii		White-fingered mud crab
Membranipora sp.		Coffin-box bryozoan

RESULTS AND DISCUSSION

Water Quality

Salinity, temperature, dissolved oxygen, conductivity, pH and secchi depth were measured *in situ* at all stations for both sampling events. Water quality data for all depths at all stations during both the late summer (September 1998) and spring (May 1999) cruises are found in the *Year 17 Data Report*. Variations in water quality values throughout the water column

were generally small, indicating that no vertical stratification occurred. The exception was a small difference in salinity seen at Back River station MDE-27 in September. Spatial variation was also minimal within both seasons. Consequently, the following discussion focuses on seasonal variation within the bottom waters.

The variations seen in bottom salinities between September 1998 and May 1999 were typical of seasonal variations in the northern region of Chesapeake Bay. Bottom salinities in September 1998 (Table 3-3) fell within the mesohaline category (5.0 to 12.0 parts per thousand, ‰) and ranged from 6.0 to 8.7 ‰ (average = 7.6 ‰ ± 0.7 ‰). In September 1998, the lowest bottom salinity (6.0‰) was found at reference station MDE-36. This benthic sampling station is the northernmost and is most likely to be influenced by freshwater influx from the Susquehanna River. The highest bottom salinity was found at reference station MDE-13 (8.7‰), a southern station more distant from northern freshwater influxes. Surface and bottom salinities never differed by more than 0.2‰ at individual stations with the exception of MDE-27 (surface = 5.8‰, bottom = 7.7‰). This difference is to be expected due to the station's position at the mouth of the Back River station, a source of fresh water.

In May 1999, bottom salinities ranged from 3.2 ‰ to 7.0 ‰ (Table 3-4, average = 5.4 ‰ ± 1.2 ‰), straddling the oligohaline and mesohaline regimes. The highest bottom salinity was found at reference station MDE-22 (7.0‰), the southernmost station. The lowest bottom salinities were found at Hawk Cove stations MDE-29 and MDE-30 (3.4‰ and 3.2‰, respectively). Both of these stations are northwest of HMI and within the path of freshwater influx from the Back River. Differences between surface and bottom salinities were more variable in May 1999 (0‰-2.4‰) than in September 1998, but no stratification was seen. Salinity of the waters around HMI in May 1999 were higher than salinity seen around nearby Pooles Island in May 1998. This may have been related to prolonged drought conditions starting in summer 1998.

Bottom water temperatures in September 1998 were warm with an average of 23.9 °C ± 1.0 °C (Table 3-3, range = 22.8 °C -27.7 °C). In May 1999, temperatures were seasonably cooler with an average of 16.8 °C ± 1.0 °C (Table 3-4, range = 15.4 °C -18.4 °C). The difference between surface and bottom temperatures was <2° C for all stations in both seasons.

Secchi depths increased marginally in May 1999 (Table 3-4, range = 0.6 m-2.4 m, average=1.5 m ± 0.5 m) over those seen in September 1998 (Table 3-3, range = 0.8 m-1.7 m, average=1.1 m ± 0.2). Turbidity was generally below 20 NTU at stations where it was measured (*Year 17 Data Report*).

During both seasons, dissolved oxygen (DO) concentrations remained above the water quality criterion of 5 parts per million (ppm). Bottom DO concentrations were lower in September 1998 than in May 1999. September values ranged from 5.3 to 8.1 ppm (average = 7.5 ppm ± 0.7 ppm). This is typical of late summer conditions in the northern part of Chesapeake Bay. The highest DO concentration in September (8.1 ppm) was found at three stations on the northern end of the facility: nearfield stations MDE-33 and MDE-34, and reference station MDE-36. The lowest bottom DO concentration was found at MDE-27, the Back River station, which also had the largest difference between surface water (8.3 ppm) and bottom water (5.3 ppm) DO levels. The low DO at station MDE-27 may have been related to the vertical

difference in salinity also seen at this station. Differences in DO concentration between surface and bottom waters were no more than 0.5 ppm at all other stations.

Table 3-3: Water quality parameters measured *in situ* at HMI *Nearfield, Reference* and *Back River/Hawk Cove Stations* stations on September 23, 1998.

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt; ‰)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
			Nearfield Stations					
MDE-01	XIF5505	Surface	0.5	7.5	23.4	7.6	6.8	1.0
		Bottom	3.0	7.5	23.4	7.6	6.8	
MDE-03	XIG5699	Surface	0.5	7.5	27.7	7.9	7.0	1.4
		Bottom	4.0	7.7	27.7	7.7	7.0	
MDE-07	XIF5302	Surface	0.5	7.9	23.8	7.2	6.8	1.2
		Bottom	5.0	7.8	23.7	7.3	6.9	
MDE-09	XIF4806	Surface	0.5	7.9	23.8	7.6	6.9	1.7
		Bottom	5.0	8.0	23.7	7.5	6.9	
MDE-16	XIF4615	Surface	0.5	8.0	23.8	7.5	6.9	1.2
		Bottom	3.5	8.0	23.7	7.3	6.9	
MDE-17	XIF4285	Surface	0.5	8.5	23.7	7.4	6.9	1.2
		Bottom	4.0	8.4	23.8	7.3	6.8	
MDE-19	XIF4221	Surface	0.5	8.1	23.9	7.4	6.9	1.2
		Bottom	4.0	8.1	23.9	7.3	6.9	
MDE-24	XIF4372	Surface	0.5	7.9	23.6	7.5	6.9	1.0
		Bottom	1.5	8.0	23.7	7.4	6.8	
MDE-33	XIF6008	Surface	0.5	7.2	23.6	8.1	7.0	1.0
		Bottom	1.0	7.2	23.6	8.1	7.1	
MDE-34	XIF5805	Surface	0.5	7.2	23.7	8.1	7.0	0.8
		Bottom	1.0	7.2	23.7	8.1	7.0	
MDE-35	XIF6407	Surface	0.5	7.0	23.7	7.8	6.8	0.8
		Bottom	3.0	7.2	23.7	8.0	7.1	
			Reference Stations					
MDE-13	XIG3506	Surface	0.5	8.7	23.7	7.7	7.0	1.2
		Bottom	4.0	8.7	23.7	7.5	6.9	
MDE-22	XIF3224	Surface	0.5	8.3	24.0	7.4	6.9	1.2
		Bottom	5.0	8.2	24.1	6.9	6.9	
MDE-36	XIG7589	Surface	0.5	5.9	23.4	7.8	7.0	1.2
		Bottom	2.5	6.0	22.8	8.1	7.1	
			Back River/Hawk Cove Stations					
MDE-27	XIF4642	Surface	0.5	5.8	23.5	8.3	8.0	0.8
		Bottom	3.0	7.7	23.2	5.3	6.9	
MDE-29	XIF5427	Surface	0.5	6.6	23.6	8.0	6.8	0.8
		Bottom	2.0	6.7	23.5	8.0	6.8	
MDE-30	XIF5925	Surface	0.5	7.3	23.7	7.3	6.8	0.8
		Bottom	1.5	7.3	23.7	7.3	6.8	

Table 3-4: Water quality parameters measured *in situ* at HMI *Nearfield, Reference* and *Back River/Hawk Cove Stations* stations on May 10 & 11, 1999. (Note that measurements were taken at station MDE-35 on both days.)

MDE Station	7-Digit Code	Layer	Depth (m)	Salinity (ppt)	Temp. (C)	Dissolved Oxygen (mg/l)	pH	Secchi Depth (m)
			Nearfield Stations					
MDE-01	XIF5505	Surface	0.5	4.1	18.6	12.6	7.7	1.8
		Bottom	3.0	5.4	17.1	12.3	7.7	
MDE-03	XIG5699	Surface	0.5	4.9	17.0	13.1	7.7	1.3
		Bottom	4.3	6.2	16.0	11.6	7.5	
MDE-07	XIF5302	Surface	0.5	4.2	18.1	13.2	7.8	1.7
		Bottom	4.0	6.2	16.0	11.7	7.4	
MDE-09	XIF4806	Surface	0.5	3.9	18.0	13.0	7.7	1.7
		Bottom	4.1	6.3	15.9	11.8	7.4	
MDE-16	XIF4615	Surface	0.5	5.4	17.0	12.2	7.6	1.4
		Bottom	2.8	6.2	16.0	11.4	7.5	
MDE-17	XIF4285	Surface	0.5	4.1	17.5	12.7	7.7	1.8
		Bottom	3.3	6.4	15.8	11.5	7.5	
MDE-19	XIF4221	Surface	0.5	6.0	16.0	10.4	7.4	1.0
		Bottom	3.5	6.1	15.8	10.1	7.4	
MDE-24	XIF4372	Surface	0.5	3.9	17.3	10.8	7.6	1.0
		Bottom	1.0	4.1	16.9	10.5	7.5	
MDE-33	XIF6008	Surface	0.5	3.5	19.0	12.9	7.8	2.2
		Bottom	1.3	4.3	17.9	13.7	7.7	
MDE-34	XIF5805	Surface	0.5	5.2	17.8	11.9	7.7	1.2
		Bottom	1.0	5.2	17.7	11.9	7.7	
MDE-35 (5/10/99)	XIF6407	Surface	0.5	4.2	18.6	9.9	7.7	2.4
		Bottom	2.5	5.1	17.0	9.9	7.8	
MDE-35 (5/11/99)	XIF6407	Surface	0.5	4.2	18.6	8.9	7.8	1.5
		Bottom	2.1	4.2	18.1	9.5	7.8	
			Reference Stations					
MDE-13	XIG3506	Surface	0.5	4.3	17.0	12.4	7.7	2.2
		Bottom	3.7	6.7	15.7	11.1	7.4	
MDE-22	XIF3224	Surface	0.5	5.6	16.0	9.5	7.7	0.6
		Bottom	4.1	7.0	15.4	7.9	7.4	
MDE-36	XIG7589	Surface	0.5	3.8	18.5	9.0	7.4	1.6
		Bottom	2.1	4.5	17.7	8.9	7.4	
			Back River/Hawk Cove Stations					
MDE-27	XIF4642	Surface	0.5	3.7	19.7	12.0	8.9	0.6
		Bottom	2.7	5.5	17.3	8.5	8.0	
MDE-29	XIF5427	Surface	0.5	3.1	18.9	10.1	7.9	1.6
		Bottom	1.4	3.4	18.3	10.3	8.0	
MDE-30	XIF5925	Surface	0.5	3.1	20.0	9.8	7.7	2.1
		Bottom	1.8	3.2	18.4	10.3	8.0	

May DO concentrations were high compared to September (range = 7.9 ppm-13.7 ppm, average 10.7 ppm ± 1.5 ppm). This relationship is expected due to the lower temperatures and higher freshwater influx typical of the spring. The highest bottom DO concentration for May was found at nearfield station MDE-33 (13.7 ppm) at the north end of the facility. The lowest bottom DO concentration was found at the southern reference station MDE-22 (7.9 ppm). The Back River Station, MDE-27, once again had the largest difference between surface (12.0 ppm) and bottom (8.5 ppm) DO concentrations, although both measurements were higher than in September. Surface and bottom concentrations differed by no more than 1.6 ppm at all other stations.

There was only a marginal difference in pH between September 1998 and May 1999. September bottom-water pH values for all stations were at or very near neutral (Table 3-3, range=6.8 pH units-7.1 pH units, average=6.9 ± 0.1 pH units). In May, pH values were near or just slightly above neutral (Table 3-4, range=7.4 pH units-8.0 pH units, average=7.6 ± 0.2 pH units). Differences between surface and bottom pH were low at all stations, $\leq$ 0.3 pH units in September and $\leq$ 0.4 pH units in May, except at MDE-27. At this station, it differed by 1.1 pH units in September and 0.9 pH units in May.

Table 3-5: Correlation Analysis of Summer (September) 1998 and Spring (May) 1999 HMI Year 17 water quality data. (p = 0.05, d.f. = 35, critical value of r = 0.325)

	Temperature (°C)	*pH*	*Dissolved Oxygen (mg/l)*	*Salinity (ppt)*	*Secchi Depth (m)*
Temperature, °C	1.000				
pH	**-0.797**	1.000			
Dissolved Oxygen, mg/l	**-0.794**	**0.731**	1.000		
Salinity, ppt	**0.666**	**-0.878**	**-0.666**	1.000	
Secchi Depth, m	**-0.411**	**0.479**	**0.617**	**-0.441**	1.000

Correlations in boldface are significant.

Significant relationships ($p<0.05$) were found among all the water quality parameters mentioned above (Table 3-5). Correlations found during this analysis were strong ($r \geq 0.75$), moderate (r = 0.50 to 0.74), or weak (r < 0.50). Many of these correlations are likely due to different parameters responding in similar manners to seasonal changes. For example, temperature has a moderate positive correlation with salinity (r = 0.666). Both are expected to rise from low spring values to higher summer values, temperature with increasing solar radiation, and salinity with the decreasing freshwater influx.

Temperature has a strong negative correlation with both pH (r = -0.797) and DO (r = -0.794). Concurrently, pH has a moderate positive correlation with DO (r = 0.731). These correlations support the hypothesis that increased temperatures not only affect DO concentrations directly, but also indirectly due to increased benthic metabolism. In brackish waters, such an increase in metabolism results in decreased pH by raising carbon dioxide levels.

A strong negative correlation exists between pH and salinity (r = -0.878). This result reflects the low salinities and strong freshwater influence of the upper Chesapeake Bay. In such an environment, increasing salinities during warmer seasons are still low enough that the CO_2

generated by increased benthic metabolism is not buffered; thus, the pH levels decrease (Reid and Wood 1996). A moderate negative correlation exists between salinity and DO (r = -0.666). This is expected since DO saturation is inversely related to salinity and temperature (Reid and Wood 1996). The low salinities at HMI, and the stronger correlation between DO and temperature, indicate that salinity probably did not play the major role in dissolved oxygen concentrations during the course of this study.

Secchi depth has a weak negative correlation with temperature (r = -0.411) and salinity (r = -0.441), a weak positive correlation with pH (r = 0.479), and a moderate positive correlation with DO (r = 0.617).

Surface temperature and salinity have been measured at all stations as part of all previous HMI benthic community assessment studies. However, bottom water quality measurements have only been taken consistently since Year 12. Temperatures in the Upper Chesapeake Bay vary seasonally, rising from spring temperatures in the teens (°C) to summer highs (August and September) in the mid- to upper 20's. The average bottom temperature for the Year 17 summer sampling (September 1998; 23.86 °C) was slightly lower than the average summer temperatures measured in Years 12-16 (range: 25.2 °C-26.82 °C; measured in August of each year [Duguay et al. *in review*, Duguay et al. *in press*, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995b]). Conversely, the average bottom temperature for the Year 17 spring sampling (May 1999; 16.82 °C) was a few degrees higher than the average spring temperatures measured in Years 12-14 (April; 8.82-11.70 °C [Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995b]). No spring measurements were taken in Year 15 or 16. These differences in seasonal temperatures may be influenced by the fact that Year 17 sampling events each occurred one month later than the sampling events in Years 12-16.

Salinity varies naturally with the amount of rainfall in a season. High rainfall, which leads to higher freshwater input from the Upper Chesapeake Bay rivers, leads to lower than normal salinity. Likewise, a dry year may lead to higher than average salinity due to decreased freshwater input. Salinity values are usually the lowest in the spring when freshets from Upper Bay rivers introduce large volumes of freshwater. This region of the bay typically ranges between the oligohaline (0.5‰-5‰) and mesohaline (5‰-18‰) salinity regimes (Lippson & Lippson 1997). Bottom salinities in Year 17 were within the expected ranges. Summer (September 1998) values all fell within the low mesohaline range, while spring (May 1999) values were split between oligohaline and low mesohaline. The same pattern was seen for the summer samples from Years 12, 14, and 16 and spring samples from Year 14 (Table 3-6). Year 13 and the spring of Year 12 were periods of high rainfall and, therefore, had lower salinities. Year 13's summer salinities all fell in the oligohaline range, while the spring salinities were all within the tidal freshwater range (0.1‰ -0.5‰). In Year 12, spring salinities ranged between tidal freshwater and oligohaline.

Year 17 was the first year for which secchi depth, pH, and bottom DO concentrations were measured for the HMI benthic community assessment studies; therefore, no comparisons are possible with previous years.

Table 3-6: Recent salinity trends in the bottom waters around HMI, Years 12 through 17.

Sampling Season	Bottom salinity range (‰)
Year 17	
September 1998	6.0-8.7
May 1999	3.2-7.0
Year 16	
August 1997	6.3-9.5
Year 15	
August 1996	2.9-8.4
Year 14	
August 1995	5.1-6.0
April 1995	4.3-5.7
Year 13	
August 1994	1.8-3.4
April 1994	0.1-0.5
Year 12	
August 1993	6.6-9.3
April 1993	0.1-1.6

Benthic Macroinvertebrate Community

A total of thirty-two taxa were found over two seasons of monitoring during Year 17 of benthic community studies in the vicinity of Hart-Miller Island. This is similar to the number of taxa that had been found in Years 12 through 16 (30, 30, 31, 26, and 29 taxa, respectively). Of the thirty-two taxa found in Year 17, twenty are considered truly infaunal; the other twelve, epifaunal (see Ranasinghe et al. 1994). The most common taxa were members of the phyla Annelida (segmented worms) and Arthropoda (joint-legged organisms). Eight species of annelid worms in the class Polychaeta were found during the study. Twelve species of arthropods were found. The most common arthropods were the isopods (such as *Cyathura polita*) and amphipods (such as *Leptocheirus plumulosus*). Epifaunal taxa, such as barnacles, bryozoans, and mud crabs, were found more often at stations where the substrate (sediment) contained a large amount of oyster or clam shell (Tables 3-7 and 3-8; Figure 3-2). Station MDE-24, a nearfield sand station near the southern end of HMI, had the greatest number of taxa in the late summer (21) and spring (22) compared to other stations (Table 3-9). Fewer taxa were found at the Hawk Cove stations (MDE-29 and MDE-30) than at most other stations during the late summer (10 and 8, respectively). Only station MDE-34, a nearfield sand station on the north side of HMI, had as few taxa (9) in the late summer. Station MDE-34 lies in close proximity to the former station S1 used by the University of Maryland's Chesapeake Biological Laboratory (CBL). Taxa richness has been consistently low in this area throughout the years (Duguay et al. *in review*, Duguay et al. *in press*, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995b). The number of taxa was higher at most stations in the spring due to seasonal recruitment (Table 3-10). Station MDE-30, in Hawk Cove, had the fewest taxa (13) in the spring.

Table 3-7: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 17 late summer sampling (September 1998), by substrate and station type.

Taxon	Average Abundance, All Stations	Total Abundance, All Stations	Substrate			Station Type		
			sand	shell	mud	Near-field	Ref.	Hawk Cove
Nematoda	6	102	10	0	7	7	2	6
Carinoma tremephorus	41	698	61	30	37	55	26	6
Bivalvia	1	13	0	0	1	1	0	0
*Mytilopsis leucophaeata**	7	115	2	14	6	6	15	0
Macoma balthica	3	58	13	0	1	5	0	0
Macoma mitchelli	24	410	64	8	14	29	19	11
Rangia cuneata	761	12934	1579	98	692	950	235	593
Heteromastus filiformis	4	64	2	6	4	2	13	0
Eteone heteropoda	21	365	27	8	25	19	4	47
Hobsonia florida	8	128	24	3	2	10	6	0
Marenzelleria viridis	41	704	67	21	39	42	47	34
Neanthes succinea	203	3443	234	346	125	228	290	21
Polydora cornuta	158	2682	360	5	136	145	43	318
Streblospio benedicti	1354	23014	1091	512	1845	815	629	4053
Tubificidae	163	2765	139	147	180	141	337	66
*Balanus improvisus**	87	1478	0	362	4	99	130	0
*Rhithropanopeus harrisii**	27	454	13	85	7	30	36	6
Cyathura polita	64	1088	75	46	67	72	53	45
Chiridotea almyra	31	525	131	0	0	48	0	0
*Edotea triloba**	16	275	50	10	4	25	0	0
Ameroculodes spp. complex	20	339	66	2	8	27	9	4
*Apocorophium lacustre**	15	250	53	2	4	22	2	0
Gammarus spp.	2	38	6	3	0	3	0	0
Leptocheirus plumulosus	97	1651	21	3	173	9	290	226
*Melita nitida**	36	608	0	66	38	20	79	51
Chironomidae	169	2874	6	29	304	27	98	759
Coelotanypus spp.	2	26	0	0	3	2	0	0
*Neomysis americana**	1	13	0	2	1	1	0	2
*Mysidopsis bigelowi**	1	13	2	0	1	1	2	0
Membranipora spp.*	25035	425594	602	100712	2260	26577	44416	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

In the late summer, the numerically most abundant taxa found in the vicinity of HMI during Year 17 were the clam *Rangia cuneata*, the polychaete worms *Streblospio benedicti* and *Neanthes succinea*, oligochaete worms in the family Tubificidae, and larvae of the insect family Chironomidae (midges). The average abundance of each taxon (in organisms per square meter) found at each station during the late summer is provided in Table 3-11. Large numbers of the polychaete worm *Streblospio benedicti* were present at the Back River and Hawk Cove stations (MDE-27, MDE-29 and MDE-30) in September. The clam worm *Neanthes succinea* was especially common at stations where the sediment contained a large amount of shell (Tables 3-7 and 3-8). These species have been among the most abundant throughout the course of the studies at HMI (Duguay et al. *in review*, Duguay et al. *in press*, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995b).

In spring, the numerically most abundant taxa were the clam *Rangia cuneata*, the annelid worm *Marenzelleria viridis*, and the amphipod *Leptocheirus plumulosus*. The average abundance of each taxon (individuals per square meter) found at each station during the spring is provided in Table 3-12. Large numbers of small juveniles of these three species were found at most stations in May. These three taxa accounted for over 50% of the individuals found at any station at that time. However, relatively few were found at the mouth of the Back River (station MDE-27) compared to other stations. Large numbers of the polychaete worm *Streblospio benedicti* were present at the Back River and Hawk Cove stations (MDE-27, MDE-29 and MDE-30) in May.

Table 3-8: Average and total abundance (individuals per square meter) of each taxon found at HMI during Year 17 spring sampling (May 1999), by substrate and station type.

Taxon	Average Abundance All Stations	Total Abundance All Stations	*Substrate*			Station Type		
			sand	shell	mud	Near-field	Ref.	Hawk Cove
Nematoda	4	64	11	0	2	5	2	0
Carinoma tremephorus	44	742	40	42	46	45	47	34
*Mytilopsis leucophaeata**	7	115	11	8	4	9	6	0
Bivalvia	18	314	62	11	2	28	0	2
Macoma spp.	9	154	0	18	9	8	21	0
Macoma balthica	190	3226	197	224	171	184	273	126
Macoma mitchelli	40	685	53	21	43	48	41	11
Rangia cuneata	881	14976	1314	1056	611	1100	474	484
Heteromastus filiformis	16	269	13	16	17	13	38	2
Eteone heteropoda	2	26	0	2	2	0	9	0
Hobsonia florida	3	51	0	0	6	0	17	0
Marenzelleria viridis	4040	68672	9749	2880	2017	5765	710	1043
Laeonereis culveri	1	19	2	0	1	1	0	4
Neanthes succinea	181	3078	178	293	133	213	201	45
Polydora cornuta	82	1402	106	130	51	75	147	45
Streblospio benedicti	313	5325	62	74	531	120	294	1039
Tubificidae	283	4806	365	206	280	264	303	333
*Balanus improvisus**	42	717	70	88	9	59	21	0
*Rhithropanopeus harrisii**	11	179	22	19	1	16	2	0
Cyathura polita	91	1549	130	74	82	102	92	49
Chiridotea almyra	56	947	230	2	2	86	0	0
*Edotea triloba**	12	198	34	10	3	15	11	0
Ameroculodes spp. complex	211	3584	349	203	153	260	186	55
Apocorophium lacustre*	65	1101	238	13	11	94	2	21
Gammarus spp.	101	1715	216	53	71	116	36	109
Gammaridae	55	934	166	35	14	74	23	17
Leptocheirus plumulosus	3108	52838	5248	2110	2601	3286	3462	2103
Melita nitida	52	877	18	59	63	24	151	53
Chironomidae	55	941	6	2	101	18	45	203
Coelotanypus spp.	0	0	0	0	0	0	0	0
*Neomysis americana**	0	0	0	0	0	0	0	0
*Mysidopsis bigelowi**	0	0	0	0	0	0	0	0
Membranipora spp.*	26796	455526	74949	16816	9830	39280	7814	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 3-9: Summary of metrics for each HMI benthic station surveyed during the Year 17 late summer sampling cruise, September 1998. Total Infaunal Abundance and Total Abundance, excluding Bryozoa, are individuals per square meter.

Station	Total Infaunal Abundance	Total Abundance, excluding Bryozoa	Taxa Richness, All Taxa	Taxa Richness, Infauna only	Shannon-Wiener Diversity Index	Pollution Sensitive Taxa Abundance	Pollution Indicative Taxa Abundance	Benthic Index of Biotic Integrity
Nearfield Stations								
MDE-1	1562	3078	12	7	1.74	7.4%	59.8%	3
MDE-3	3494	3565	14	9	2.21	45.4%	42.1%	3
MDE-7	3469	3558	18	11	1.79	71.4%	17.5%	4
MDE-9	2029	2112	19	10	2.56	35.0%	49.5%	4
MDE-16	1382	1530	15	11	2.63	25.0%	61.1%	3
MDE-17	2150	2227	17	12	2.39	26.8%	43.5%	4
MDE-19	518	570	13	12	2.27	19.8%	64.2%	3
MDE-24	4941	5421	20	17	2.58	28.8%	48.4%	4
MDE-33	6445	6445	15	15	1.86	55.1%	18.4%	3
MDE-34	1024	1024	9	7	2.15	36.9%	0.6%	4
MDE-35	2016	2042	14	12	2.01	24.8%	66.7%	3
Reference Stations								
MDE-13	1606	2522	14	8	1.95	6.0%	41.8%	3
MDE-22	2221	2470	14	13	2.51	11.5%	42.7%	4
MDE-36	2477	2541	15	13	2.27	26.4%	64.1%	4
Back River/Hawk Cove Stations								
MDE-27	11443	12275	15	13	1.06	1.2%	91.6%	1
MDE-29	3744	3757	9	9	2.15	26.0%	56.6%	3
MDE-30	3386	3411	7	6	2.07	26.7%	64.5%	3

Total abundance was higher in the spring (May 1999) than in the late summer (September 1998) due to seasonal recruitment in the spring. In the late summer (Table 3-9, Figure 3-3a), total abundance ranged from 570 to 12,275 organisms/m^2 and averaged 3,444 organisms per square meter (individuals/m^2). This number does not include the Bryozoa, which are colonial epifauna and can reach high numeric densities on shell and other hard substrates. Average total abundance was similar between reference and nearfield stations. Abundance was highest at the Back River station (MDE-27) where pollution-tolerant worms, *Streblospio benedicti* and Tubificidae, were present in large numbers. Abundance was lowest at nearfield station MDE-19. This station lies near former CBL station S5, which was found in several earlier studies of HMI to be influenced by boat traffic at the rehandling piers (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987).

In the spring, total abundance at all stations averaged 9,981 individuals/m^2 and ranged from 3,322 to 32,032 individuals/m^2 (Table 3-10; Figure 3-3b). Large numbers of juvenile *Marenzelleria viridis* (a polychaete worm) and *Leptocheirus plumulosus* (an amphipod) resulted in very high abundance, especially at station MDE-24, a nearfield sand station on the southern side of the facility (Table 3-12). High abundance of these two taxa also resulted in abundances of over 10,000 individuals/m^2 at nearfield stations MDE-1, MDE-7, MDE-33, and MDE-34, and at reference station MDE-22. Abundance was lowest at nearfield stations MDE-19 and MDE-30, although total numbers at these stations still exceeded 3,000 individuals/m^2. Abundance was

lower in the spring compared to the late summer at stations MDE-27 and MDE-30, at the mouth of the Back River and in Hawk Cove, respectively. Abundance dropped at these stations due to decreases in the numbers of midges (Chironomidae) and the polychaete worm *S. benedicti*. *S. benedicti* was still the dominant organism at MDE-27 in the spring.

Table 3-10: Summary of metrics for each HMI benthic station surveyed during the Year 17 spring sampling cruise, May 1999.

Station	Total Infaunal Abundance	Total Abundance, Excluding Bryozoa	Taxa Richness, All Taxa	Taxa Richness, Infauna Only	Shannon-Wiener Diversity Index	Pollution Sensitive Taxa Abundance	Pollution Indicative Taxa Abundance
Nearfield Stations							
MDE-01	16057	16633	20	13	1.97	74%	2%
MDE-03	7296	7366	17	12	2.41	63%	14%
MDE-07	13171	13228	18	13	1.78	76%	1%
MDE-09	6003	6080	18	15	2.18	64%	2%
MDE-16	6515	6515	17	15	2.60	54%	8%
MDE-17	5497	5523	17	12	2.17	30%	4%
MDE-19	3360	3392	14	11	2.00	24%	0%
MDE-24	31334	32025	22	16	1.62	33%	1%
MDE-33	17600	17868	20	15	1.64	86%	1%
MDE-34	17753	18297	22	7	1.53	87%	2%
MDE-35	5350	5388	21	12	3.05	27%	25%
Reference Stations							
MDE-13	3865	4044	21	15	2.71	20%	7%
MDE-22	10131	10496	17	15	1.39	9%	5%
MDE-36	5267	5305	21	13	2.97	56%	23%
Back River/Hawk Cove Stations							
MDE-27	8038	8204	15	13	1.59	7%	20%
MDE-29	5772	5811	18	9	2.85	53%	30%
MDE-30	3302	3321	14	6	2.71	44%	41%

Total infaunal abundance and epifaunal abundance are subsets of total abundance. Infaunal abundance excludes certain organisms that have been omitted from the calculation of the B-IBI (see *Methods*). Total infaunal abundance was similar to total abundance, accounting for >90% of all organisms at most stations during both seasons. Exceptions occurred at the shell substrate stations, MDE-1 (nearfield) and MDE-13 (reference), where epifaunal taxa accounted for over 35% of the total abundance during the late summer sampling. Epifaunal taxa accounted for less than 5% of total abundance at any station during spring sampling due to high recruitment by infaunal taxa, especially *M. viridis* and *L. plumulosus*. Total abundance was generally similar between nearfield and reference stations during September. Total abundance was higher at several nearfield stations on the northern and northeastern sides of HMI compared to reference stations in the spring.

Table 3-11: Average number of individuals collected per square meter at each station during the HMI Year 17 late summer sampling cruise, September 1998.

Taxon	Station							
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19
Nematoda	0	6	0	0	0	0	0	0
Carinoma tremephorus	0	90	58	122	26	64	64	32
Bivalvia	0	0	0	13	0	0	0	0
Mytilopsis leucophaeata*	6	6	45	6	45	6	0	0
Macoma balthica	0	0	6	0	0	0	0	0
Macoma mitchelli	0	0	0	19	0	19	6	13
Rangia cuneata	77	1440	2291	595	70	237	525	6
Heteromastus filiformis	0	0	6	0	26	0	13	0
Eteone heteropoda	0	51	26	19	0	32	6	0
Hobsonia florida	0	0	0	0	0	0	0	13
Marenzelleria viridis	0	6	51	32	13	13	19	58
Neanthes succinea	493	320	282	141	787	96	550	6
Polydora cornuta	6	19	38	6	0	13	0	0
Streblospio benedicti	813	1011	429	749	352	582	550	301
Tubificidae	122	410	147	186	320	128	371	19
*Balanus improvisus**	1056	0	13	13	390	0	6	0
*Rhithropanopeus harrisii**	237	51	6	0	102	0	32	0
Cyathura polita	38	141	128	83	13	96	32	38
Chiridotea almyra	0	0	0	0	0	0	0	0
*Edotea triloba**	0	13	13	6	0	38	6	0
Ameroculodes spp. complex	0	0	0	19	0	0	6	6
*Apocorophium lacustre**	0	0	13	0	6	0	19	0
Gammarus spp.	13	0	0	0	0	0	0	0
Leptocheirus plumulosus	0	0	0	6	0	0	0	13
*Melita nitida**	218	0	0	0	45	0	0	0
Chironomidae	0	0	0	32	0	102	6	13
Coelotanypus spp.	0	0	6	19	0	0	0	0
*Neomysis americana**	0	0	0	0	0	6	0	0
*Mysidopsis bigelowi**	0	0	0	0	0	0	0	0
Membranipora spp.*	256448	2406	6	45	133248	12525	20288	627

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 3-11, continued:

Taxon	Station								
	MDE-22	MDE-24	MDE-27	MDE-29	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Nematoda	0	0	19	0	0	0	32	38	6
Carinoma tremephorus	51	134	0	19	0	19	0	19	0
Bivalvia	0	0	0	0	0	0	0	0	0
*Mytilopsis leucophaeata**	0	0	0	0	0	0	0	0	0
Macoma balthica	0	51	0	0	0	0	0	0	0
Macoma mitchelli	45	250	32	0	0	6	0	6	13
Rangia cuneata	96	1248	122	902	755	3443	186	403	538
Heteromastus filiformis	13	6	0	0	0	0	0	0	0
Eteone heteropoda	6	45	141	0	0	13	0	19	6
Hobsonia florida	0	96	0	0	0	0	0	0	19
Marenzelleria viridis	90	70	6	26	70	45	147	19	38
Neanthes succinea	45	288	58	6	0	326	0	6	38
Polydora cornuta	0	102	26	627	301	1318	0	96	128
Streblospio benedicti	288	2202	9530	1331	1299	1152	0	1178	1248
Tubificidae	602	134	173	26	0	13	0	26	90
*Balanus improvisus**	0	0	0	0	0	0	0	0	0
*Rhithropanopeus harrisii**	0	0	0	0	19	0	0	0	6
Cyathura polita	70	51	13	45	77	64	45	77	77
Chiridotea almyra	0	0	0	0	0	19	506	0	0
*Edotea triloba**	0	186	0	0	0	0	0	13	0
Ameroculodes spp. complex	0	166	13	0	0	6	90	6	26
*Apocorophium lacustre**	0	211	0	0	0	0	0	0	0
Gammarus spp.	0	13	0	0	0	6	6	0	0
Leptocheirus plumulosus	864	70	678	0	0	6	6	0	6
*Melita nitida**	192	0	154	0	0	0	0	0	0
Chironomidae	51	13	634	762	883	6	6	122	243
Coelotanypus spp.	0	0	0	0	0	0	0	0	0
*Neomysis americana**	0	0	6	0	0	0	0	0	0
*Mysidopsis bigelowi**	6	6	0	0	0	0	0	0	0
Membranipora spp.*	0	0	0	0	0	0	0	0	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Pfitzenmeyer et al. (1982) suggested that diversity, as measured by the Shannon-Wiener diversity index, would be higher in summer, when recruitment decreased and predation increased thus reducing the numbers of the dominant taxa, and lower in spring due to seasonal recruitment. Diversity has often been lowest at most stations in spring (April or May) due to an influx of juveniles, especially of the dominant species (Duguay et al. 1998, Duguay et al. 1995a, Duguay et al. 1995b, Duguay 1992, Duguay 1990, Pfitzenmeyer and Tenore 1987). In Year 17, diversity was higher at seven stations in September compared to May, but lower at eight other stations in September (Tables 3-9 and 3-10; Figure 3-4). Diversity was similar between the two seasons at the remaining two nearfield stations (MDE-7 and MDE-16). Diversity ranged from 1.06 to 2.63 in the late summer and from 1.53 to 3.05 in the spring. Diversity was lowest at the Back River/Hawk Cove stations (MDE-27, MDE-29, and MDE-30) in the late summer due to large numbers of midges (Chironomidae) and the worm *Streblospio benedicti*. Diversity was higher at these stations in the spring when numbers of midges and *S. benedicti* were lower, and additional species were found. The highest diversity of any station (3.05) was found at station MDE-35 (a

nearfield silt/clay-substrate station on the north side of HMI) in the spring. Diversity at nearfield stations was similar to diversity at reference stations in late summer and spring.

Table 3-12: Average number of individuals collected per square meter at each station during the HMI Year 17 spring sampling cruise, May 1999.

Taxon	Station							
	MDE-1	MDE-3	MDE-7	MDE-9	MDE-13	MDE-16	MDE-17	MDE-19
Nematoda	0	0	0	0	0	0	0	0
Carinoma tremephorus	26	90	58	70	58	70	51	13
Mytilopsis leucophaeata*	32	19	13	0	0	0	0	0
Bivalvia	0	186	6	0	0	45	0	0
Macoma spp.	0	0	0	0	0	0	13	70
Macoma balthica	0	0	0	128	230	243	179	422
Macoma mitchelli	0	0	0	0	6	58	70	19
Rangia cuneata	2976	800	1619	506	256	992	410	0
Heteromastus filiformis	0	0	51	6	51	6	26	6
Eteone heteropoda	0	0	0	0	6	0	0	0
Hobsonia florida	0	0	0	0	0	0	0	0
Marenzelleria viridis	8787	3680	8154	3110	205	2163	1037	365
Laeonereis culveri	0	0	0	0	0	0	0	0
Neanthes succinea	557	122	173	224	307	256	301	51
Polydora cornuta	186	0	19	58	326	6	0	0
Streblospio benedicti	13	237	0	51	45	237	77	0
Tubificidae	358	781	141	45	205	256	154	6
Balanus improvisus*	288	0	13	70	64	0	0	0
*Rhithropanopeus harrisii**	70	26	0	0	6	0	13	0
Cyathura polita	115	147	218	115	77	90	38	13
Chiridotea almyra	6	6	13	0	0	0	0	0
Edotea triloba*	19	6	13	0	19	0	0	0
Ameroculodes spp. complex	422	333	390	179	154	115	64	122
Apocorophium lacustre*	38	0	19	6	0	0	0	13
Gammarus spp.	58	45	109	38	26	13	13	115
Gammaridae	19	0	0	0	19	0	0	102
Leptocheirus plumulosus	2534	864	2221	1446	1894	1958	3066	2054
Melita nitida*	128	19	0	0	90	0	13	19
Chironomidae	0	6	0	26	0	6	0	0
Coelotanypus spp.	0	0	0	0	0	0	0	0
*Neomysis americana**	0	0	0	0	0	0	0	0
*Mysidopsis bigelowi**	0	0	0	0	0	0	0	0
*Membranipora sp**.	54656	3136	20800	29760	6400	6208	20864	0

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Table 3-12: Continued.

Taxon	Station								
	MDE-22	MDE-24	MDE-27	MDE-29	MDE-30	MDE-33	MDE-34	MDE-35	MDE-36
Nematoda	0	0	0	0	0	45	0	13	6
Carinoma tremephorus	45	19	19	51	32	6	45	51	38
*Mytilopsis leucophaeata**	0	0	0	0	0	0	26	6	19
Bivalvia	0	64	0	6	0	0	0	6	0
Macoma spp.	64	0	0	0	0	0	0	6	0
Macoma balthica	512	621	307	70	0	64	102	269	77
Macoma mitchelli	58	154	32	0	0	19	38	173	58
Rangia cuneata	58	224	13	998	442	2323	1907	346	1107
Heteromastus filiformis	64	45	0	6	0	0	6	0	0
Eteone heteropoda	19	0	0	0	0	0	0	0	0
Hobsonia florida	0	0	0	0	0	0	0	0	51
Marenzelleria viridis	243	9440	198	1946	986	12582	13293	800	1683
Laeonereis culveri	0	6	0	13	0	0	0	0	0
Neanthes succinea	154	115	70	38	26	160	314	70	141
Polydora cornuta	0	6	0	90	45	218	198	134	115
Streblospio benedicti	410	13	1171	1062	883	0	0	698	429
Tubificidae	38	179	358	531	109	154	346	480	666
Balanus improvisus*	0	0	0	0	0	0	282	0	0
*Rhithropanopeus harrisii**	0	13	0	0	0	6	45	0	0
Cyathura polita	134	45	45	64	38	160	166	19	64
Chiridotea almyra	0	256	0	0	0	422	237	6	0
*Edotea triloba**	0	58	0	0	0	13	58	0	13
Ameroculodes spp. complex	128	544	45	96	26	243	275	173	275
*Apocorophium lacustre**	0	608	6	38	19	250	96	0	6
Gammarus spp.	64	512	38	218	70	218	90	70	19
Gammaridae	45	282	6	26	19	269	115	26	6
Leptocheirus plumulosus	8090	18797	5658	397	256	710	621	1869	403
*Melita nitida**	365	13	160	0	0	0	38	32	0
Chironomidae	6	13	77	160	371	6	0	141	128
Coelotanypus spp.	0	0	0	0	0	0	0	0	0
*Neomysis americana**	0	0	0	0	0	0	0	0	0
*Mysidopsis bigelowi**	0	0	0	0	0	0	0	0	0
Membranipora spp.*	16064	0	0	0	0	742	295917	0	979

Note: Abundance of *Membranipora* spp. represents an estimate of the number of zooids present per square meter.
* Indicates taxa that are considered epifaunal for the purposes of calculating the B-IBI (see Ranasinghe et al. 1994)

Four taxa found during Year 17 benthic monitoring were designated as "pollution-sensitive" according to Weisberg et al. (1997). These were the clams *Rangia cuneata* and *Macoma balthica*, the isopod *Cyathura polita*, and the polychaete worm *Marenzelleria viridis*. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-sensitive taxa (PSTA) ranged from 1.2% to 71.4% with an average of 28% over all stations in the late summer (Table 3-9; Figure 3-5a) and from 7% to 87.1% with an average of 48% over all stations in the spring (Table 3-10; Figure 3-5b). PSTA increased at most stations in spring compared to late summer due to seasonal recruitment primarily of *M. viridis*. PSTA decreased slightly within the same period at reference station MDE-22 and nearfield station MDE-35 where large numbers of juvenile amphipods

(*Leptocheirus plumulosus*) were present. These amphipods are not classified as either pollution-sensitive or pollution-indicative. PSTA was slightly higher at sand stations (average in late summer = 41.5%; average in spring = 61.6%) than at shell (average in late summer = 14.5%; average in spring = 56.8%) or silt/clay stations (average in late summer = 27.7%; average in spring = 41.5%). This was due to higher numbers of the clam *Rangia cuneata* at sand stations. The average PSTA was slightly higher at nearfield stations than at reference stations; this difference could be attributed to differences in substrate (i.e., there were no sand reference stations). The average PSTA for the Back River/Hawk Cove stations was intermediate between the reference and nearfield stations.

Three taxa found during Year 17 benthic monitoring were designated as "pollution-indicative" according to Weisberg et al. (1997). These were the polychaete worms *Streblospio benedicti* and *Eteone heteropoda,* and the midge *Coelotanypus sp.* In addition, the oligochaete worms (Tubificidae) found during the study were classified as pollution-indicative because past studies have shown that *Limnodrillus hofmeisteri*, which is considered pollution-indicative, is common around HMI. Relative abundance of these taxa was calculated as a proportion of total infaunal abundance. Relative abundance of pollution-indicative taxa (PITA) ranged from 0.6% to 91.6% with an average of 49% in the late summer (Tables 3-9; Figure 3-5b). PITA was lower at all stations in the spring due to high seasonal recruitment of other, non-classified taxa. Average PITA at the Back River/Hawk Cove stations (70.9% and 29.8%, late summer and spring, respectively) was higher than at Reference stations (49.5% and 10.1%, late summer and spring, respectively) during both seasons. Both the numeric and relative abundance of *S. benedicti* was higher at the Back River/Hawk Cove stations than at other stations. PITA varied considerably among nearfield stations but was generally similar to reference stations.

Length frequency distributions for the three most common infaunal clams were determined. The clams *Rangia cuneata*, *Macoma balthica*, and *Macoma mitchelli* were measured to the nearest millimeter. *Rangia*, which ranged in size from 2 mm to over 45 mm, were grouped into size classes at 5-mm intervals. *Macoma*, which ranged in size from 1 mm to 26 mm, were grouped into size classes of 2-mm increments. As in previous years, *Rangia* was the most common clam species in the waters around HMI (Table 3-7 and 3-8). The most common size classes of *Rangia* were the 15-20 mm and 21-25 mm size classes in both spring and late summer. These size classes have often been the most common (Duguay et al. *in review*, Duguay et al. *in press*, Duguay et al. 1999, Duguay et al. 1998, Duguay et al. 1995b). Based on information in Hopkins et al. (1973), these clams are probably 1-2 years old and may be close to sexual maturity. Spring recruitment of *Rangia* was especially high in these class ranges, although increases were seen in all size classes. Figure 3-6 shows the average number of *Rangia* found at stations around HMI per square meter per station in late summer and spring.

Both species of *Macoma* were generally rare around HMI during year 17. *M. mitchelli* was more common than *M. balthica* in late summer (September), but less common in the spring when large numbers of juvenile *M. balthica* were present. *M. mitchelli*, which was found at only 12 stations around HMI, was more common at sand stations than silt/clay or shell stations (Tables 3-7 and 3-8). Spring recruitment of *M. mitchelli* was high in all size ranges (Figure 3-8).

Most *M. balthica* clams found at any station during either season were less than 10 mm in length (Figure 3-8). In September, *M. balthica* was found only at station MDE-24, a nearfield

sand station on the southern end of HMI, and at station MDE-7, a nearfield station east of HMI with a significant amount of sand in the sediment (Table 3-7). Spring recruitment of *M. balthica* was high, especially in the 3-4 mm size range (Figure 3-8). *M. balthica* was slightly more common at shell stations than at sand or silt/clay stations. *M. balthica* was about 1 1/2 times more abundant at reference stations than at nearfield stations in spring.

The Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) was calculated for all stations based on late summer (September 1998) data only, because the B-IBI has not been developed for spring. Four metrics – total infaunal abundance, the Shannon-Wiener diversity index, relative abundance of pollution-sensitive taxa, and relative abundance of pollution-indicative taxa – were used to calculate the B-IBI. A restoration goal has been established for the Chesapeake Bay based on the B-IBI (B-IBI score greater than or equal to 3.0) and B-IBI scores for the seventeen benthic stations studied during Year 17 were compared to this benchmark. Seven benthic stations, including the two silt/clay Reference stations, exceeded the restoration goal, which indicates minimal disturbance at these stations (Figure 3-9). The third reference station (MDE-13) had a slightly lower B-IBI score and marginally met the restoration goal (i.e., B-IBI equal to 3.0). Seven other stations, including nearfield and Back River/Hawk Cove stations, also marginally met the restoration goal. Nearfield station MDE-19 and Back River station MDE-27 had B-IBI scores of less than 3.0. Total infaunal abundance affected B-IBI scores at both of these stations. At MDE-19 total infaunal abundance was lower than optimal (518 individuals/m^2); whereas at MDE-27, it was much higher than optimal (11,443 individuals/m^2). Relative abundance of the worm *Streblospio benedicti*, a species classified as "pollution-indicative" (Weisberg et al. 1997), was high at both stations.

CONCLUSIONS AND RECOMMENDATIONS

As in past years, no significant differences were seen between reference and nearfield stations. Most of the faunal differences among stations can be explained on the basis of the dominant substrate type (i.e., shell, sand or silt/clay). Only two stations, MDE-19 (nearfield) and MDE-27 (Back River), failed to meet the Restoration Goal of a B-IBI score of 3.0. These two stations appear to be impacted by factors other than HMI. MDE-19 lies to the east of the island near an area previously reported as being impacted by barge traffic (see Results and Discussion). MDE-27, at the mouth of the Back River, is more representative of conditions in the Back River than a result of impacts from dredged material placement at HMI.

The Hart-Miller Island Dredged Material Containment Facility should continue to operate until the year 2009. To date, there have been no measurable impacts from HMI on the benthic community in the adjacent area. It is recommended that benthic community monitoring continue throughout the remainder of the period during which HMI is actively utilized for placement of dredged material in order to be certain there are no significant impacts to the benthic community. In addition, it is recommended that a thorough statistical study be undertaken to determine longer-term trends in benthic community condition surrounding HMI.

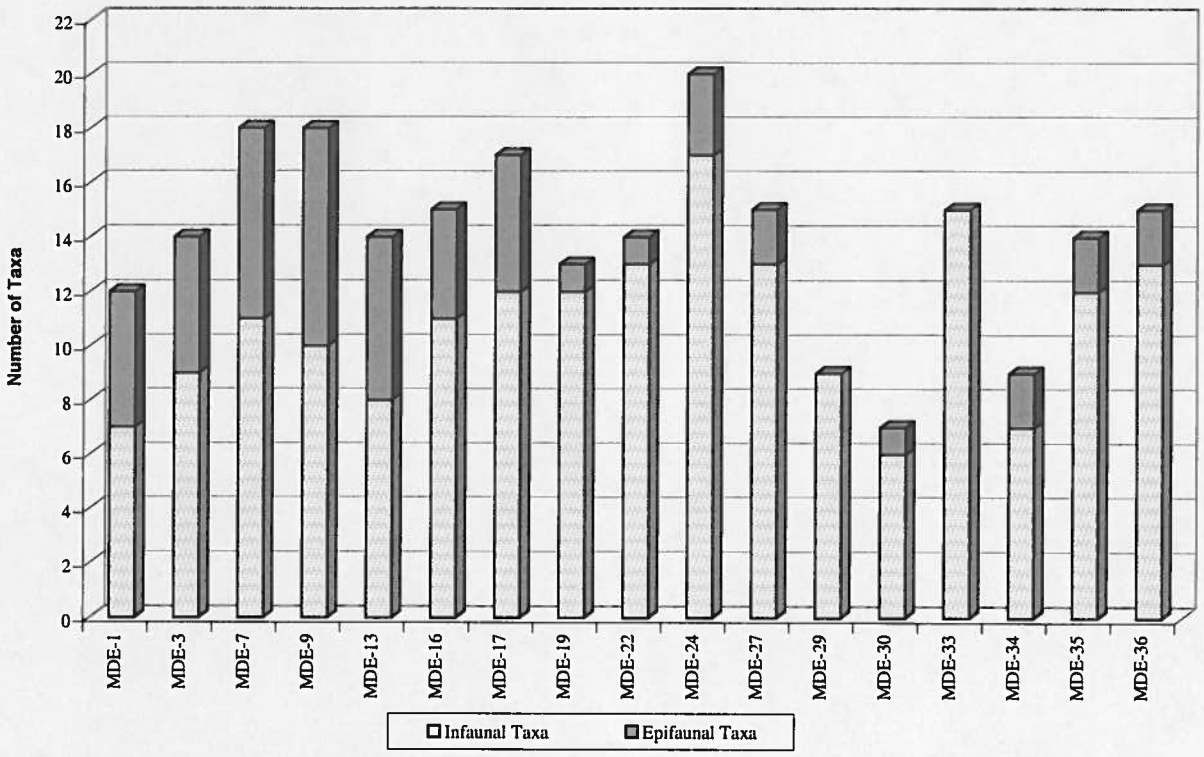

Figure 3-2a: Taxa Richness (Infaunal and Epifauna), Hart-Miller Island Exterior Monitoring Program, Year 17, September 1998.

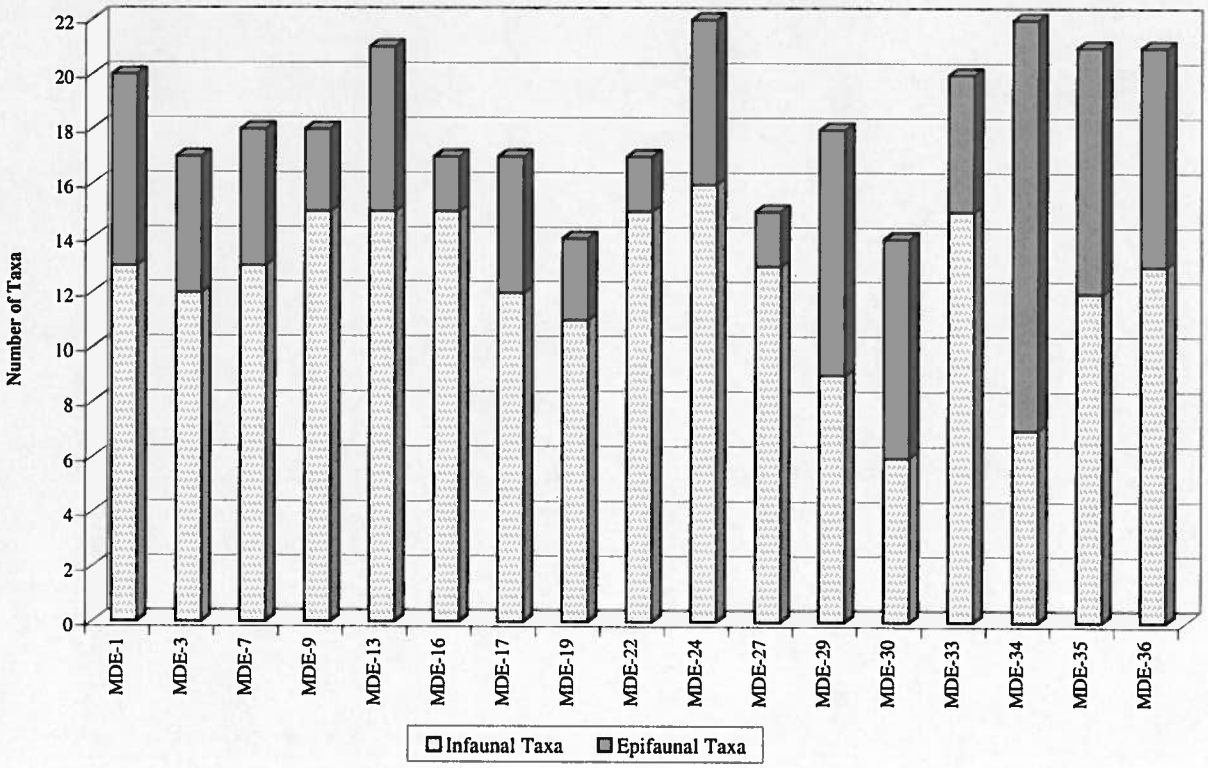

Figure 3-2b: Taxa Richness (Infaunal and Epifauna), Hart-Miller Island Exterior Monitoring Program, Year 17, May 1999.

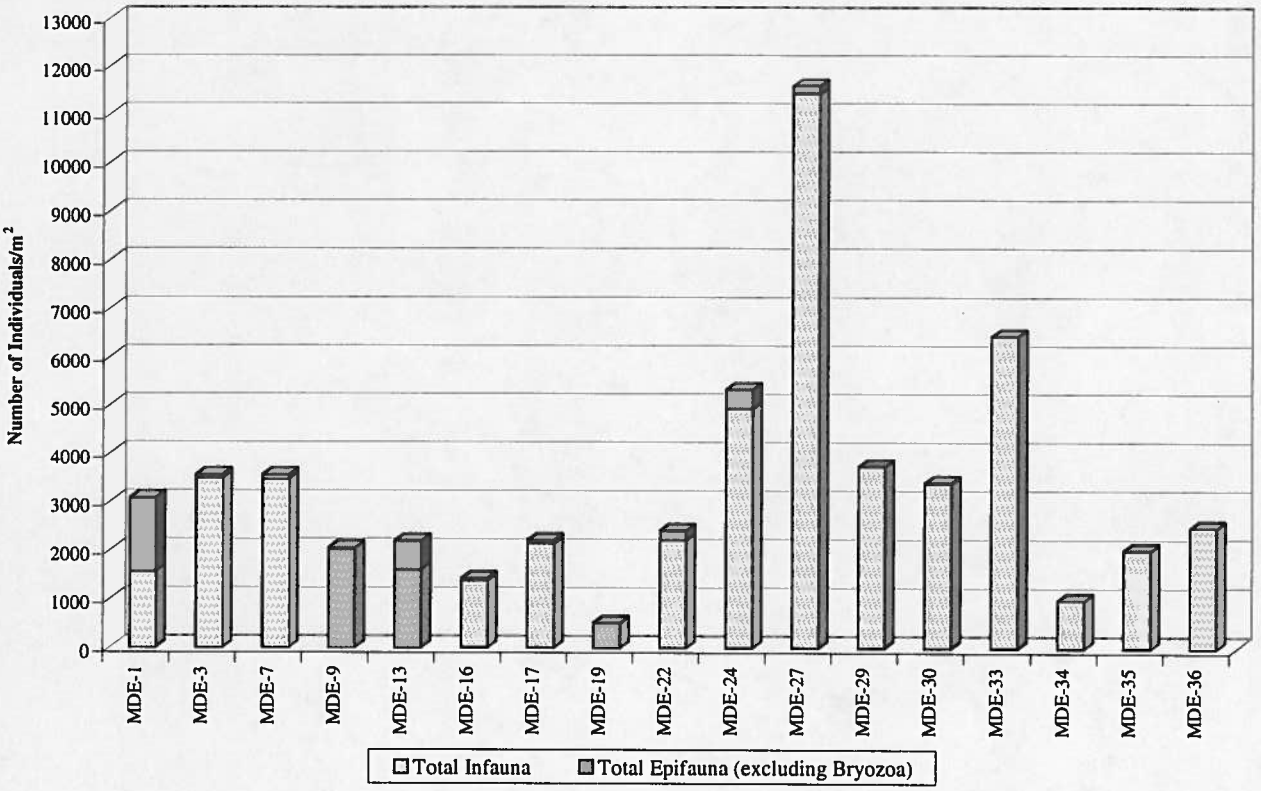

Figure 3-3a: Total Abundance of Infauna and Epifauna, Hart-Miller Island Exterior Monitoring Program, Year 17, September 1998.

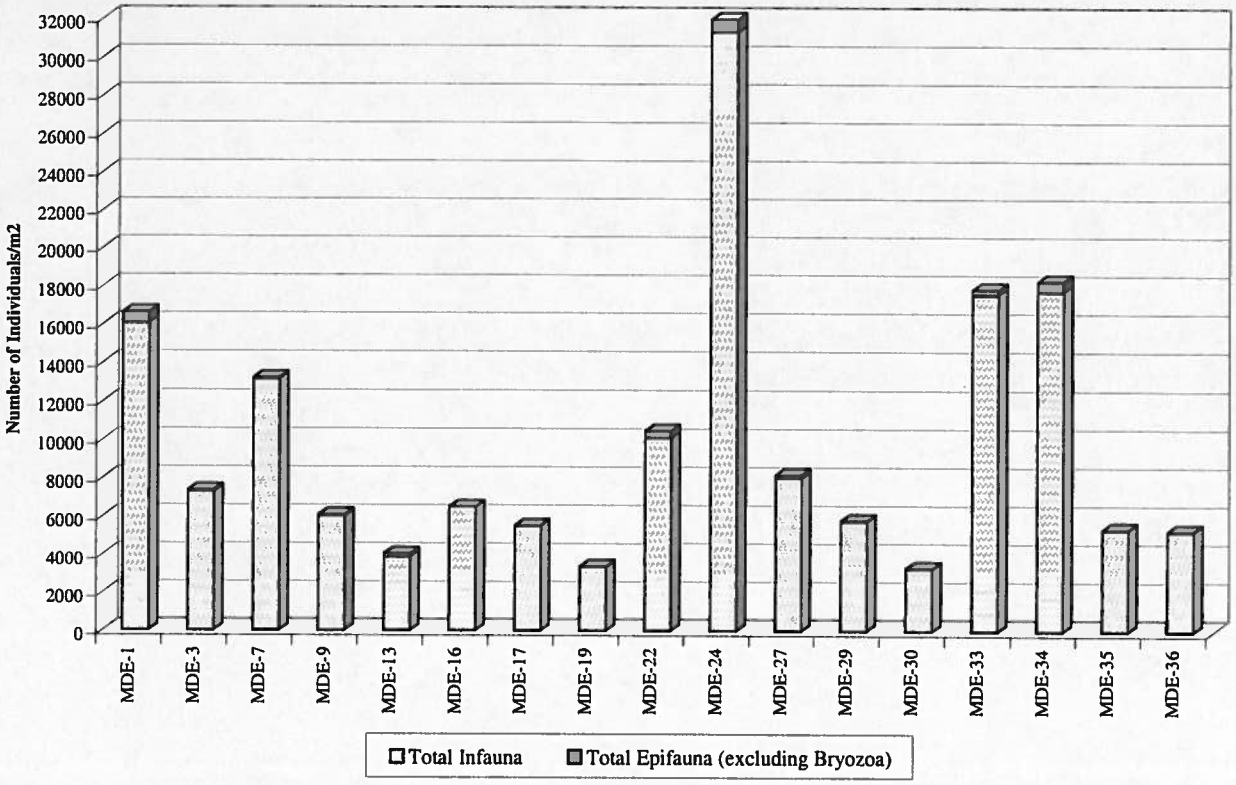

Figure 3-3b: Total Abundance of Infauna and Epifauna, Hart-Miller Island Exterior Monitoring Program, Year 17, May 1999.

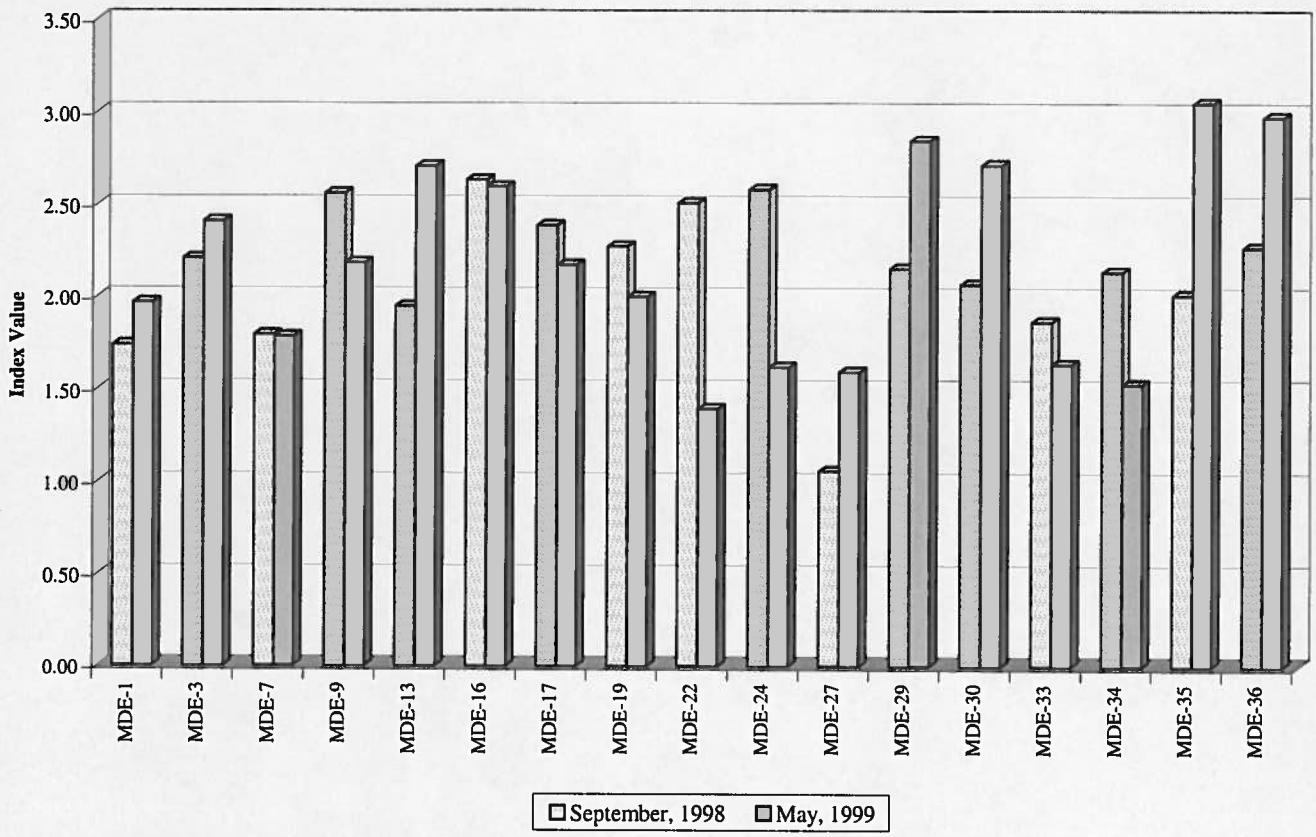

Figure 3-4: Shannon-Wiener Diversity Index, Hart-Miller Exterior Monitoring Program, Year 17, September 1998 and May 1999.

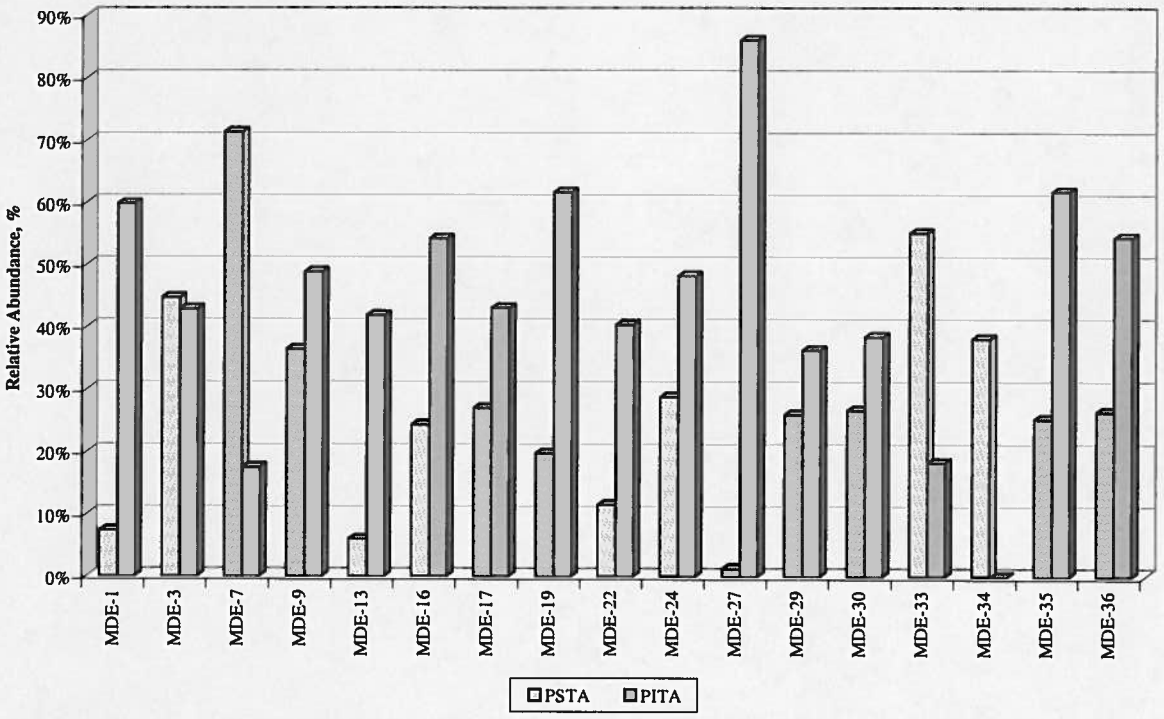

Figure 3-5a: Relative Abundance of Pollution-Sensitive (PSTA) and Pollution-Indicative (PITA) Taxa, Hart-Miller Island Exterior Monitoring, Year 17, September 1998.

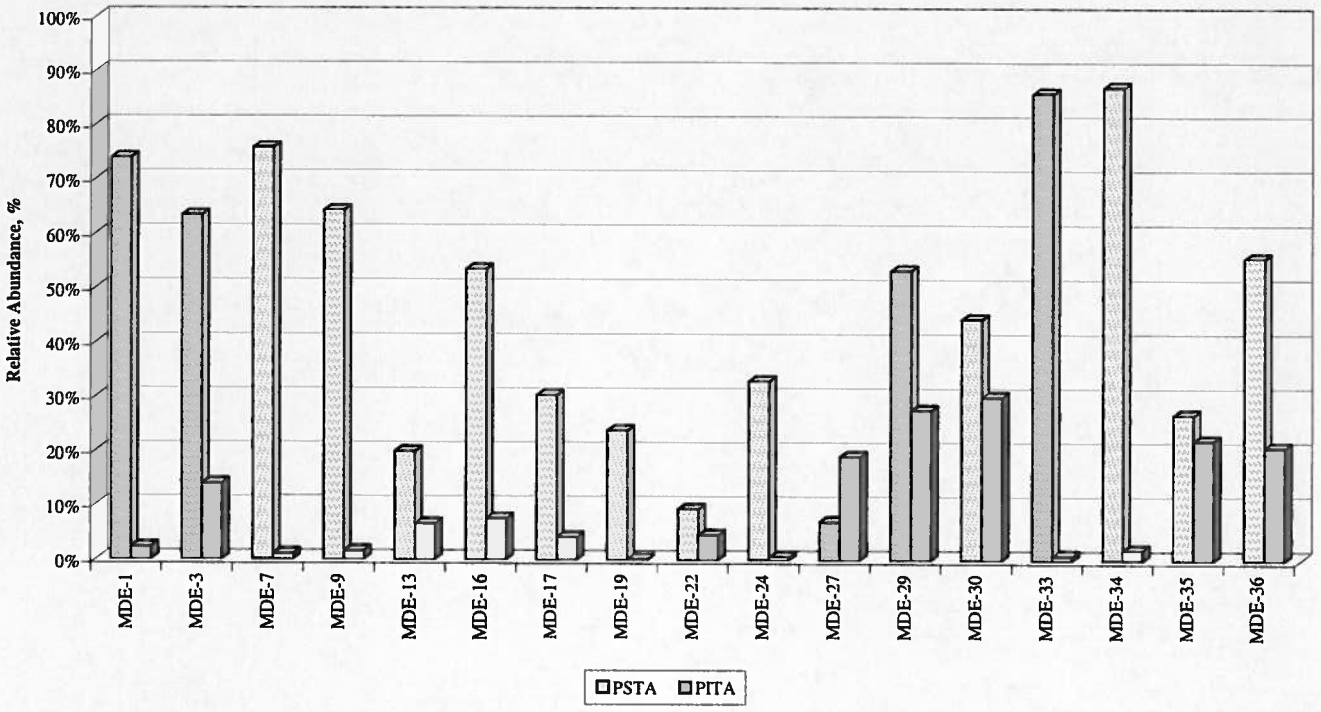

Figure 3-5b: Relative Abundance of Pollution-Sensitive (PSTA) and Pollution-Indicative (PITA) Taxa, Hart-Miller Island Exterior Monitoring, Year 17, May 1999.

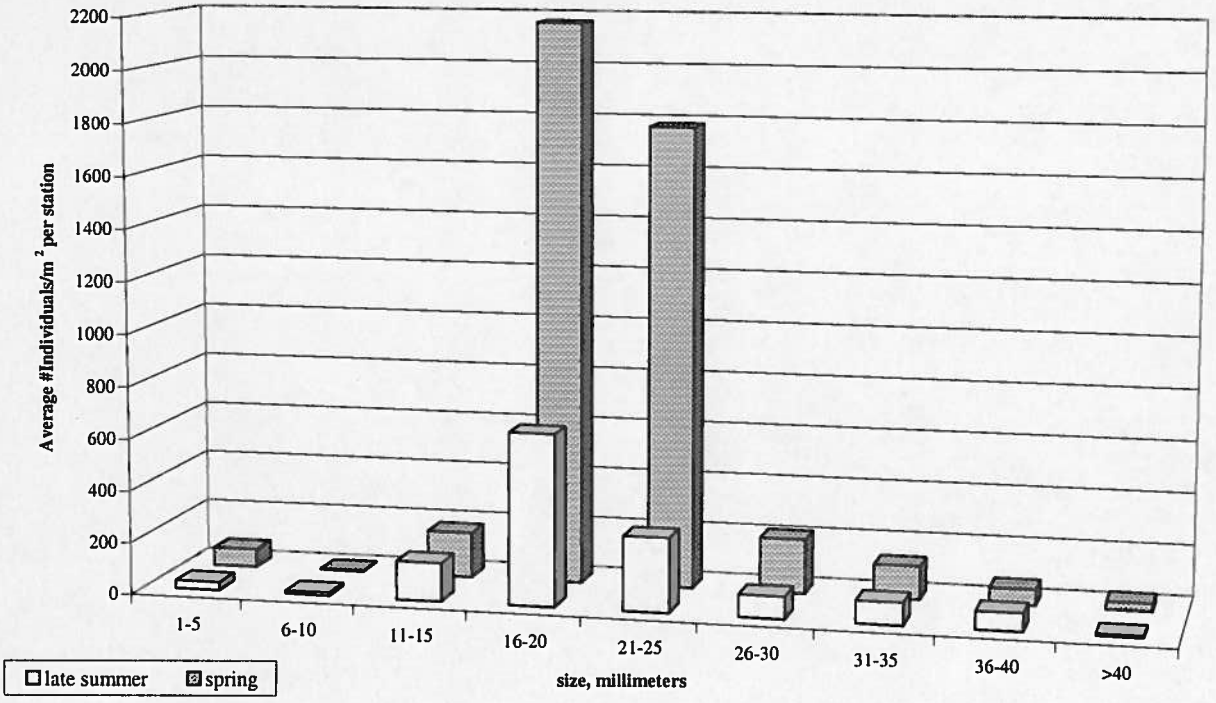

Figure 3-6: Distribution of Various Size-Classes of *Rangia cuneata* found during Year 17 of the Hart-Miller Island Exterior Monitoring Program, September 1998 and May 1999.

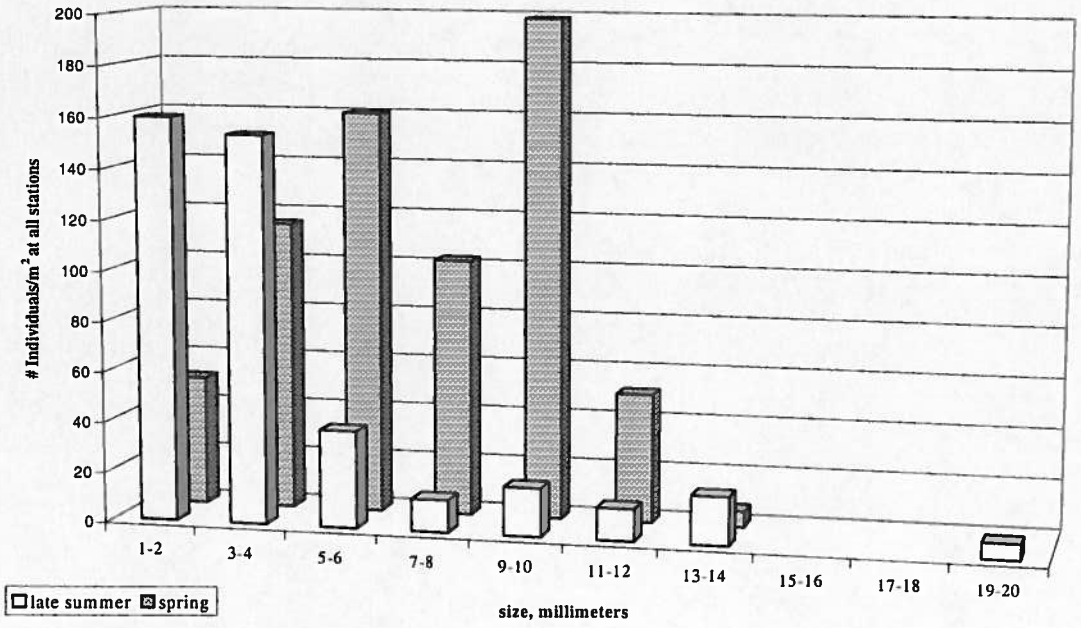

Figure 3-7: Distribution of Various Size-Classes of *Macoma mitchelli* Found During Year 17 of the Hart-Miller Island Exterior Monitoring Program, September 1998 and May 1999.

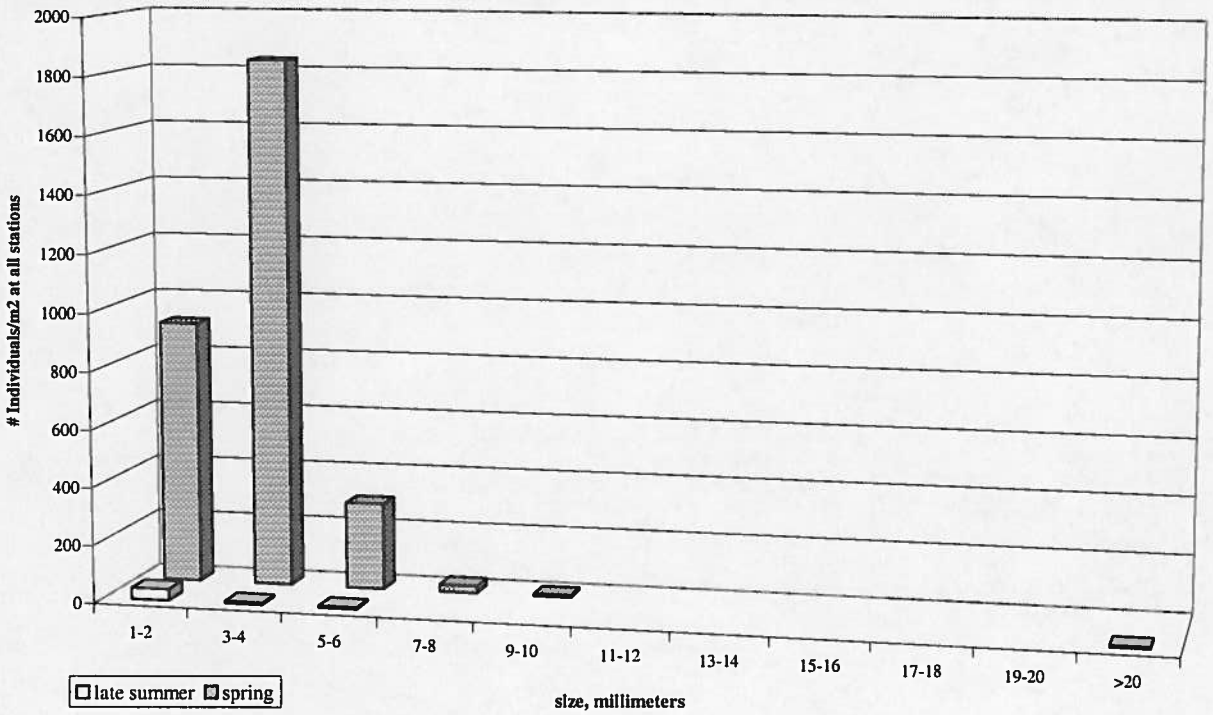

Figure 3-8: Distribution of Various Size-Classes of *Macoma balthica* Found During Year 17 of the Hart-Miller Island Exterior Monitoring Program, September 1998 and May 1999.

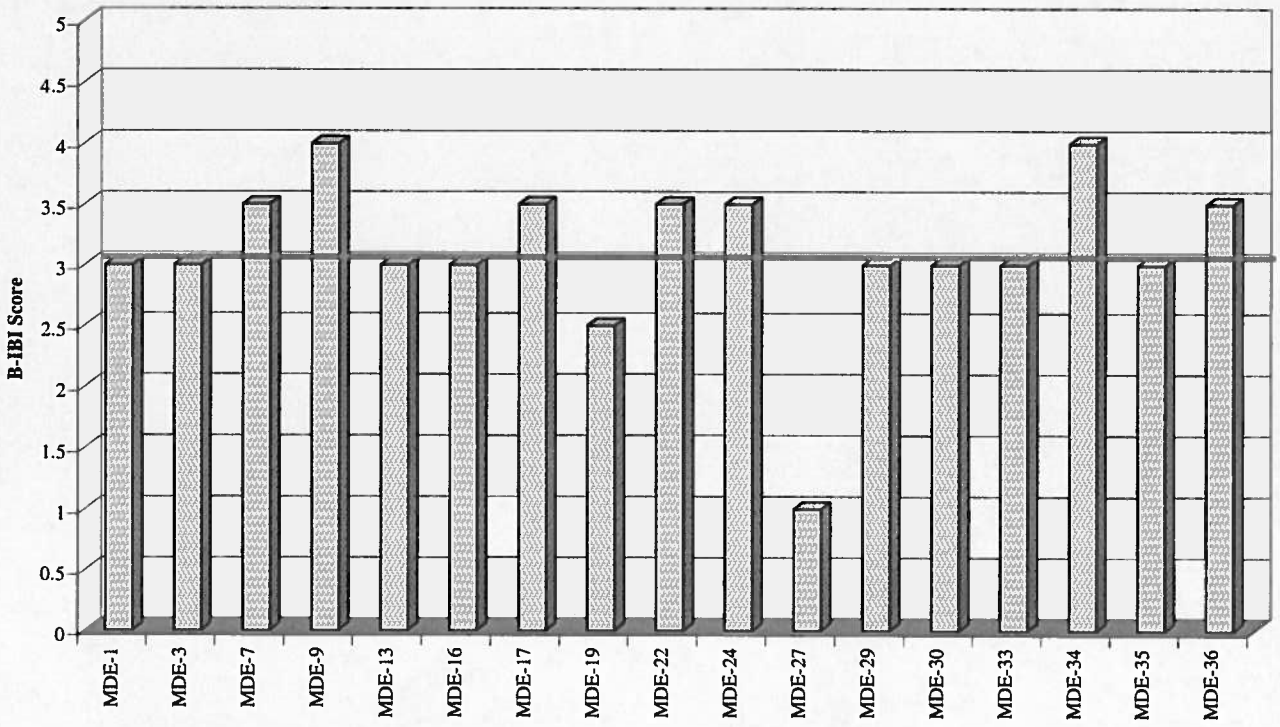

Figure 3-9: Benthic Index of Biotic Integrity Scores, Hart-Miller Island Exterior Monitoring, Year 17, September 1998.

CHAPTER IV: ANALYSIS OF CONTAMINANTS IN BENTHIC ORGANISMS AND SEDIMENTS COLLECTED NEAR HART-MILLER ISLAND (Project 4)
MONITORING YEAR 17 (September 1998 - April 2000)

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INTRODUCTION

Beginning in 1981, sediments and biota have been analyzed for trace metals and organic contaminants as part of the Exterior Monitoring Program for the Hart-Miller Island (HMI) Dredged Material Containment Facility. The objective of this program was to document long-term trends in contaminant levels in the vicinity of HMI. While this monitoring effort has been partially successful as a screening tool for releases of highly contaminated material from HMI, it has not been able to reliably describe spatial and temporal trends in the levels of contaminants that are present at low levels, nor has it adequately investigated other potential sources (i.e., Back River, Baltimore Harbor or the Susquehanna River) of contaminants to this region. Previous analytical methods used in the monitoring program prior to 1996 were not sensitive enough to detect all the trace metals or organic contaminants measured during more recent studies, some of which are Toxics of Concern (CBP 1994) and are important for assessing impacts from the HMI facility.

This study augments and expands the existing HMI Exterior Monitoring Program to continue to address the above issues. Linked sediment and clam samples were collected during the fall of 1998 and the spring of 1999. These sites, where possible, corresponded with those sampled in 1996 and 1997. Sediments and clams were collected at the same time at the same stations in order to correlate the benthic tissues burdens with sediment chemistry. The results of this study are compared with those of 1996 and 1997 to assess interannual and seasonal variability. The results of this study, in the context of the previous work, should provide the information required by the long term HMI monitoring program.

OBJECTIVES

The objective of this study is to provide sensitive, high-quality information on the concentrations of present day trace metals and organics in surficial sediments and clams surrounding HMI during the 17th year of exterior monitoring, and to document any seasonal changes. Specific objectives were:

1. Collect sediment and biota samples in the fall of 1998 and spring of 1999 in association with biota collections for benthic monitoring by MDE, and sediment for metals by MGS;

2. To determine the concentrations of target trace elements and organic contaminants in surficial sediments around HMI. For organic contaminants, 10 sites (plus two reference sites) were chosen from the 30 sites that were sampled by MGS for trace metal and ancillary parameter analysis. Sediment metal analysis focuses on those metals not measured by MGS, specifically mercury (Hg), monomethylmercury (MMHg), silver (Ag), and arsenic (As);

3. To determine the concentrations of contaminants in the brackish water clam *Rangia*

cuneata resident in the sediments around HMI at the 12 sites where sediment samples were taken for sediment organic analysis. The same suite of organic analytes were measured, and, in addition to Hg, MMHg, and Ag, and As, clams were analyzed for cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb), and zinc (Zn); and

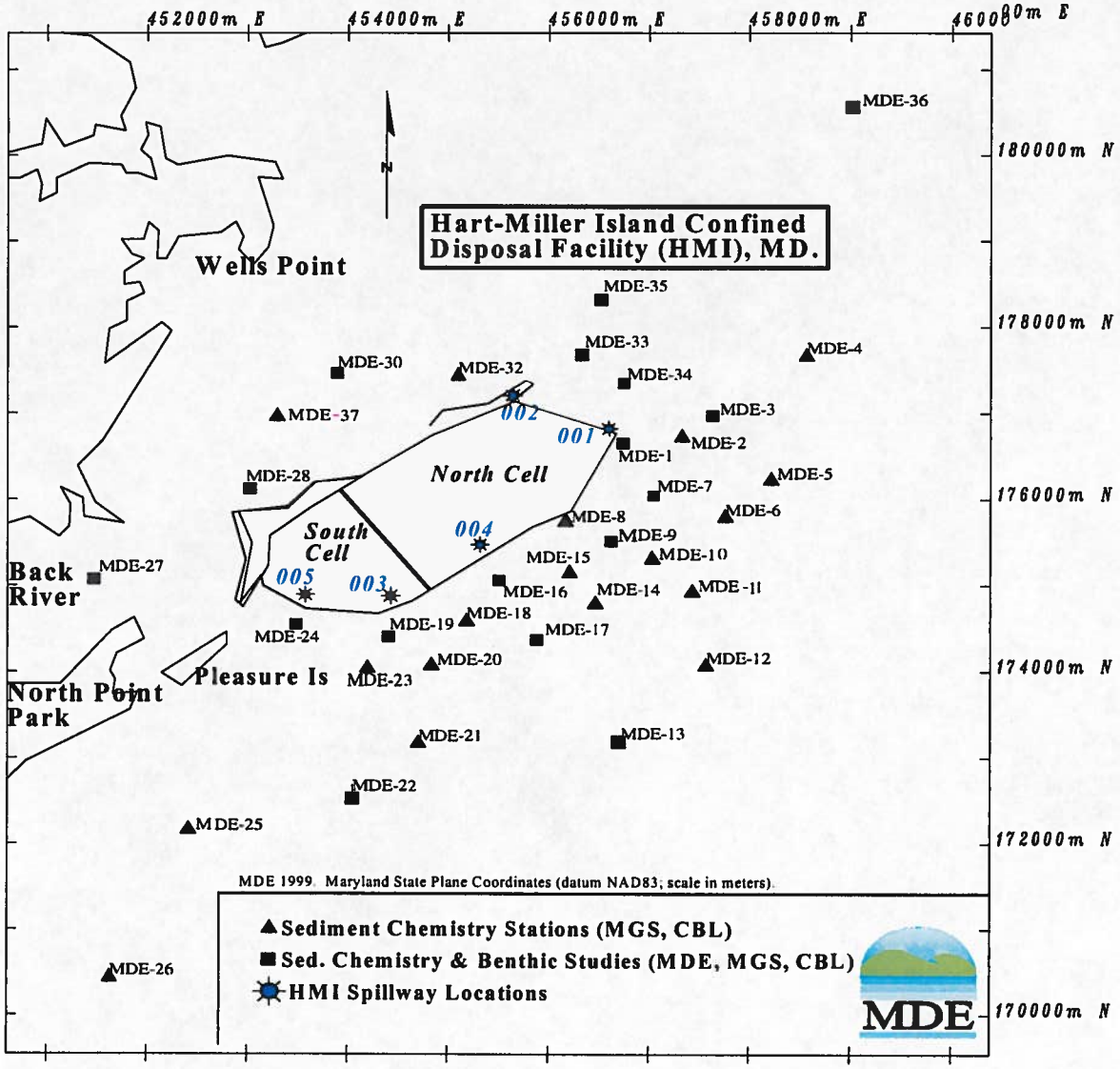


Figure 4-1: Map of revised sampling sites surrounding Hart-Miller Island Dredged Material Containment Facility.

4. To compare results of these analyses to established benchmarks and to existing data measured elsewhere and to ascertain the factors controlling the concentration in the clams relative to that of the sediment. Comparison with the 1996 and 1997 data will be made, where possible, and levels of contaminants in HMI sediments and clams will be compared to published sediment quality and consumption advisory benchmarks, respectively.

METHODS AND MATERIALS

Sampling Procedures

Samples were collected from sites designated by the revised sampling plan, developed by the Maryland Department of the Environment (Figure 4-1), using the R/V Thomas C. Hopkins, Jr. in September 1998 and the R/V Discovery in April 1999.

Sediment samples were collected from 12 of the 36 designated sample sites (see below) from grabs of the upper 20 cm by Van Veen sampler on the September 1998 cruise. Triplicate samples were taken at stations MDE 9 and MDE 31. During the April 1999 cruise, sediment samples were collected using a dip-galvanized Petersen sampler to collect the upper 10 cm at all 36 designated sites. On both cruises trace metal samples were collected using plastic spatulas to collect subsamples that were several centimeters from the top and avoiding the sides of the sampler to minimize the possibility of contamination from the sampling device. Sediments were placed in 18 oz. Whirl-Pak™ bags and were kept cooled in an ice chest or refrigerator until they could be processed in the laboratory.

Clam (*Rangia cuneata*) samples were taken for trace element sampling from 12 sites in September 1998 and 11 sites in April 1999 around Hart-Miller Island using a modified dredge. The sites were MDE1, MDE3, MDE9, MDE16, MDE17, MDE19, MDE22, MDE24, MDE27, MDE30, MDE35 and MDE36. Several pulls of the dredge were taken at each site to provide enough clams for contaminant analysis. In April 1999, clams were not obtained from MDE-24. Clams were placed in zip-lock bags and stored on ice until they were returned to the laboratory. Many clams less than 3.5 cm in length were taken, but most clams selected for analysis were >3.0 cm. In the laboratory, the clam samples were cataloged and divided into subsamples for trace metal and organic contaminant analysis. For organic analysis, composite samples of clams from each site were prepared by removing fresh clams whole from their shells with a stainless steel scalpel. All body fluids were retained in the sample. The scalpel was cleaned with methanol between each sample set to avoid cross contamination between stations. Tissue was placed in a clean glass jar with a Teflon-lined lid and stored in the dark below 0°C. For metals analysis, clams were removed whole from their shells with a Teflon-coated spatula. Most of the water and body fluids were allowed to drain. The spatula was acid rinsed between each site to avoid cross contamination between sites. The clam bodies from each site were homogenized in a plastic blender with a stainless steel blade. Unused samples were returned to their respective bags and stored in the freezer until further analysis.

Analytical Procedures for Metals

Methods used for both metals and organic contaminants are similar to those described in detail in Dalal et al. (1999). For metals, a subsample of each trace metal sample (sediments and clams) was used for dry weight determination. Weighed samples were placed in a VWR Scientific Forced Air Oven at 60^{0}C overnight. Upon drying, samples were then reweighed and a dry/wet ratio was calculated.

Another subsample of clam tissue (5 g wet weight) was placed in acid-cleaned flasks for further digestion, using USEPA Methods (USEPA Methods; Keith 1991). Ten mL of 1:1 HNO_3 was added and the slurry was mixed and covered with a watch glass. The sample was heated to 95^{0}C and allowed to reflux for 15 minutes without boiling. The samples were cooled, 5 mL of concentrated HNO_3 was added, and then they were allowed to reflux for another 30 minutes. This step was repeated to ensure complete oxidation. The watch glasses were removed and the resulting solution was allowed to evaporate to 5 mL without boiling. When evaporation was complete and the samples cooled, 2 mL of 30% H_2O_2 was added. The flasks were then covered and returned to the hot plate for warming. The samples were heated until effervescence subsided. We continually added 30% H_2O_2 in 1 mL aliquots with warming until the effervescence was minimal. No more than a total of 10 mL of H_2O_2 was added to each sample. Lastly, 5 mL of concentrated HCl and 10 mL of deionized water were added and the samples refluxed for 15 minutes. The samples were then cooled and filtered through Whatman No. 41 filter paper by suction filtration and diluted to 50 mL with deionized water. Sediments were digested in a similar fashion. The clam and sediment homogenates were then analyzed using a Hewlett Packard model 4500 Inductively Coupled Plasma Mass Spectrometer for Ag, As, Cd, Cr, Cu, Ni, Pb, and Zn concentration. These techniques are similar to USEPA Method 1632.

Samples for mercury (1-3 g wet weight) were digested in a solution of 70% sulfuric/30% nitric acid in Teflon vials, heating overnight in an oven at 60^{0}C (Mason et al. 1995). The digestate was then diluted to 10 mLs with distilled-deionized water. Prior to analysis, the samples were further oxidized for 30 minutes with 2 mLs of bromine monochloride solution. The excess oxidant was neutralized with 10% hydroxylamine solution and the concentration of mercury in an aliquot of the solution was determined by tin chloride reduction cold vapor atomic fluorescence (CVAFS) detection after gold amalgamation in accordance with protocols outlined in USEPA Method 1631 (Mason et al. 1993).

Samples for methylmercury were distilled after adding a 50% sulfuric acid solution and a 20% potassium chloride solution (Horvat et al. 1993, Bloom 1989). The distillate was reacted with a sodium tetraethylborate solution to convert the nonvolatile MMHg to gaseous MMHg. The volatile adduct was purged from solution and recollected on a graphitic carbon column at room temperature. The MMHg was then thermally desorbed from the column and analyzed by cryogenic gas chromatography with CVAFS. Detection limits for Hg and MMHg were based on three standard deviations of the blank measurement.

Analytical Methods for Organic Contaminants

Whole clams were removed from their shells using a stainless steel scalpel and stored in pre-cleaned glass jars with Teflon lined lids. The clams were separated by site and collection date. In Fall of 1998 the clams were also separated into two size classes, based on shell length, prior to homogenization. The clams' bodies were homogenized in a stainless steel tissue blender and returned to their respective sample jars. The clam homogenates were extracted and purified using the method described by Kucklick et al. (1996). For this method, a subsample of clam homogenate, 5 g wet weight, is removed and ground with anhydrous sodium sulfate (~50 g). A perdueterated polyaromatic hydrocarbon (PAH) cocktail (d_8-napthalene, d_{10}-fluorene, d_{10}-fluoranthene, d_{12}-perylene) and a noncommercial polychlorinated biphenyl (PCB) solution (IUPAC #'s 14, 65, 166) are added as surrogates to each sample to track extraction efficiency. The mixture is then extracted in a Soxhlet apparatus with 250 mL of dichloromethane (DCM) for 24 hours. The extracts are then concentrated to 2 mL using a vacuum rotary evaporator and transferred into hexane. Each sample is transferred to a 4 ml Waters autosampler vial with sample and rinses amounting to approximately 4 mL. Gravimetric lipid analysis is performed on each sample with subsampled fractions determined gravimetrically (Kucklick et al. 1996). Samples are again concentrated in similar fashion as above, then solvent exchanged to hexane. To remove lipids the extracts are then eluted with 25 mL petroleum ether over 4 g deactivated Alumina [6% (w/w) water]. After concentrating, the extracts are spiked with a perdueterated PAH mixture (d_{10}-acenapthene, d_{10}-phenanthrene, d_{12}-benz[*a*]anthracene, d_{12}-benzo[*a*]pyrene, d_{12}-benzo[*g,h,I*]perylene) for quantification of PAH's. The samples are then analyzed using a Hewlett Packard 5890 gas chromatograph (GC) with a HP-5MS (cross linked 5% phenyl methyl siloxane) capillary column (30m x 0.25mm x 0.25um film thickness) and a HP-5972 series mass spectrometer (MS) for PAH's (Ko and Baker 1995). Each sample is separated after GC/MS analysis into two fractions with 35 mL of petroleum ether and 50 mL of DCM/PET (1:1), respectively, over 8 g of deactivated Florisil (2.5% (w/w) water (Kucklick et al.1996). The first fraction (F-1), contains PCBs and 1-100%, by weight of the less polar organochlorine pesticides [heptachlor (100%), 4,4-DDT (40%), 4,4-DDE (100%), t-nonachlor (24%), heptachlor (1%), 4,4-DDT(44%)]. The second fraction, (F-2), contains 56-100% of the more polar organochlorine pesticides [a-HCH (100%), g-HCH (100%), c-chlordane (100%), t-chlordane (100%), t-nonachlor (76%), heptachlor (99%), heptachlor epoxide (100%), dieldrin (100%), 4,4-DDD (100%), 4,4-DDT (56%)]. Both fractions are solvent exchanged to hexane and concentrated to ~ 1 mL.

PCB congeners are analyzed by gas chromatography using a J&W Scientific DB-5 capillary column (60m x 0.32mm, 0.25 μ m film thickness) coupled with an electron capture detector. Individual PCB congeners are identified and quantified using the method of Mullins et al. (1985) using the noncommercial PCB congeners IUPAC 30 and 204 as internal standards. After quantification of PCB congeners, the two Florisil fractions from each sample are recombined and pesticides are quantified by gas chromatography (30 m DB-5 column) with negative chemical ionization mass spectrometric (NCI-MS) detection. Chemical ionization with methane reagent gas is used. Pesticides are identified by their chromatographic retention times

and confirmed by the relative abundance of negative fragments (confirmation ions) relative to the quantification fragment. Five-point calibration curves are used for each pesticide analyzed. Polychlorinated biphenyl congener 204 is used as the internal standard for the pesticide quantification.

Quality Assurance/ Quality Control

Metals

For the samples processed, two blanks were carried throughout the entire sample preparation and analytical process for both metals and for mercury. One field replicate was taken and two lab duplicates (sample splits) were prepared to measure reproducibility of replicate samples. The lab replicate consisted of a split homogenized sample that was digested and then analyzed separately. Digestates were often analyzed twice, in addition to the replicates described above. Reported values (Table 4-1) are the average if duplicate analysis was performed.

Table 4-1: Quality assurance/quality control parameters for trace metals for Year 17 . All reported values are in μg g^{-1} dry weight (ppm).

	Ag	As	Cd	Cr	Cu	Hg	MMHg	Ni	Pb	Zn
Detection Limit	0.571	0.719	0.019	0.570	0.446	0.005	0.004	0.321	0.040	1.600
SRM Oyster (measured)	1.71	12.56	3.37	1.76	55.82	.112	.037	2.67	0.60	862
SRM Oyster (certified)	1.68 ± 0.15	14.0 ± 1.2	4.15 ± 0.38	1.43 ± 0.46	66.3 ± 4.3	0.064 ± .0067	N.C.	2.25 ± 0.44	0.371 ± 0.014	830 ± 57
SRM Sediment (measured)	N.C.	7.29	0.15	20.27	7.47	0.04	N.A.	94.10	9.05	35.50
SRM Sediment (certified)	N.C.	6.23 ± 0.21	0.148 ± 0.07	40.9 ± 1.9	10.01 ± 0.34	N.C.	N.C.	22.5	11.7 ± 1.2	48.9 ± 1.6

N.C.= not certified, N.A.= not analyzed

Laboratory measured values were compared to certified values for target metals in standard reference material (SRM) 1566a oyster tissue and in a sediment SRM 1646a (Table 4-1). Our measured values agree with the SRM certified values for both sediment and tissue overall. Detection limits were calculated as three times the standard deviation of the mean of five blanks.

Organic Contaminants

Method detection limits were calculated from the minimum quantity detectable either by the analytical instrument or by the quantity significantly greater than analyte masses in field blanks. Instrument detection limits were calculated as the mass of each analyte required to generate a signal three times greater than the background noise. Blank-based detection limits were calculated as three times the mass of analyte detected in the field matrix blank. Therefore, the overall method limit is determined either by the sensitivity of the instrument's detector or by the cleanliness of the sampling and analytical procedure. In this report, we present only those concentrations of target organic analytes that exceed the method detection limit.

Method accuracy for organic contaminant analysis is determined by quantification of target analytes in National Institute of Standards and Technology (NIST) Standard Reference Materials. We verified the methods used in this study by analyzing NIST SRM 1974a (Mussel Tissue) and 1941a (Marine Sediment). Our results correlate well with certified values for organochlorine pesticides and PAHs.

Overall method efficiency of each sample is assessed by adding surrogate PAHs and PCB congeners to the samples prior to extraction. A suite of surrogate compounds with different volatilities allows us to assess the overall method efficiency for each class of analytes (Table 4-2).

Table 4-2: Method efficiency for HMI clams and sediment as determined by surrogate PAH's and PCB's.

	1998		1999	
	Clam	**Sediment**	**Clam**	**Sediment**
d10 Fluorene	72 ± 14 %	83 ± 3 %	83 ± 7 %	81 ± 13 %
d10 Fluoranthene	71 ± 7 %	70 ± 5 %	90 ± 8 %	90 ± 16 %
d12 Perylene	94 ± 7 %	95 ± 3 %	83 ± 6 %	82 ± 14 %
Surr 14	74 ± 8 %	94 ± 7 %	100 ± 10 %	72 ± 13 %
Surr 65	70 ± 5 %	84 ± 7 %	78 ± 28 %	53 ± 12 %
Surr 166	79 ± 8 %	101 ± 6 %	88 ± 6 %	61 ± 21 %

RESULTS AND DISCUSSION

Trace Metals

Sediments

The results of trace metal analysis for sediments for September 1998 and April 1999 are shown in Figures 4-2 and 4-3, respectively. Overall, average trace metal concentrations in sediments fell into 3 categories:

1) metals with levels at or below 1 $\mu g\ g^{-1}$ (e.g. Ag, Cd, Hg and MMHg);
2) metals at intermediate concentrations of 10 to 60 $\mu g\ g^{-1}$ (e.g. As, Cr, Cu); and
3) metals at concentrations of greater than 60 $\mu g\ g^{-1}$ (e.g. Ni, Pb, and Zn).

These numbers are generally in agreement with other studies of low to moderately impacted estuaries (Table 4-3), as well as values obtained by CBL for HMI in 1996 and 1997 (Figure 4-4), the Baltimore Harbor Mapping Study (Baker et al. 1997) and the northern Chesapeake Bay in general (MDE 1991). Trace metal concentrations were considerably lower than those reported in the Back River (MDE 1999), suggesting that trace metal concentration in sediments around the island are not elevated.

The relationship between 1998 and 1999 individual trace element concentrations is shown in Figure 4-5. Overall, the range in values obtained for HMI are comparable between the two years, with a few exceptions. For example, Zn levels were consistent across the years and with previous data. In 1999, metal concentrations for Ag, Cu, Hg, and Pb were higher than in 1998, however the differences were within a factor of three and are not considered significant given the variability of the long term data. Also notable is that As and Ni concentrations were higher in 1998 and 1999 than in previously reported years. For As, the increase is less than a factor of two and may just reflect yearly variability, a change in analytical procedures (from Hydride Generation Atomic Absorption Spectrometry to Inductively Coupled Plasma- Mass Spectroscopy [ICP-MS]) or may be a true increase in the As load within the sediment. Differences in instrumentation are the most likely reason for the changes and reflect the greater sensitivity and precision of the ICP-MS. Nickel concentrations were four fold higher in sediments in 1998 and 1999 than in 1996 and 1997. This difference appears to be analytical in nature, since the sediment SRM for Ni was approximately four times the NIST reported value (Table 4-1). The tissue SRM values are consistent with those certified. The values obtained for both SRMs for Ni in analysis of samples for HMI for 1999/2000 (Year 18; MDE, in progress) are comparable to the certified values and thus the SRM data for Year 17 appear anomalous. The values obtained for Ni in Fall 1999 for sediment range from 20 - 115 ppm and are more comparable to the 1996 and 1997 data. Thus, we conclude that the Ni data for sediment for Year 17 are elevated, likely as a result of an analytical interference during analysis. The most likely source of this positive interference is Ni contamination in the mass spectrometer (MS) as a result of acid interference with the Ni in the interface cones that separate the ICP from the MS. This problem does not currently appear to be occurring (Year 18; MDE, in progress). Given the fact that the higher Ni SRM values are likely an analytical problem, it is also probable that the Ni

concentrations in the sediments are also elevated due to the analytical artifact. This should be noted when comparing values for Ni in the figures.

Table 4-3: A comparison of HMI trace metal data from Sept. 1998 and April 1999 to relevant published values.

Element	Sediment (ppm, DW)	Biota (ppm, DW)
Zinc	Unpolluted site 18 Bay 10-229 Sewage dump site 252 (54-410) Harbors 229-11,000 *Eisler et al. 1977* ***HMI sediment (1998) 171*** ***HMI sediment (1999) 162***	Clam 81-115 ; Max. 510 *Sprague, 1986* ***HMI clam (1998) 141*** ***HMI clam (1999) 140***
Cadmium	Marine sediment 0.03-1 *Korte 1983* ***HMI sediment (1998) 0.322*** ***HMI sediment (1999) 0.318***	Clam (estuaries, UK)1-40; Max 60 *Bryan and Hummerstone 1978* ***HMI clam (1998) 0.93*** ***HMI clam (1999) 0.06***
Arsenic	Bay 20-230 *NRCC 1978* ***HMI sediment (1998) 25*** ***HMI sediment (1999) 26***	Oyster 10.3 *Eisler 1981* ***HMI clam (1998) 0.6*** ***HMI clam (1999) 0.5***
Chromium	California/Wisconsin 40-120 *Towill et al. 1978* ***HMI sediment (1998) 31.0*** ***HMI sediment (1999) 39.0***	Clam 3.3-24.7 *Phelps et al. 1975* ***HMI clam (1998)3.9*** ***HMI clam (1999)30.0***
Lead	Chesapeake Bay, 1979–81 1–134 *Di Giulio and Scanlon 1985* Industrialized area, Nile River Max. 1,800 *Fayed and Abd-El-Shafy 1985* ***HMI sediment (1998) 32.2*** ***HMI sediment (1999) 83.0***	**Clam, Chesapeake Bay 0.6-27** ***Di Giulio and Scanlon 1985*** ***HMI clam (1998) 3.3*** ***HMI clam (1999) 2.4***
Mercury	U.S., non contaminated area 0.02–0.06 *Martin and Hartman 1984* Minamata Bay, Japan 28.0–713.0 *Skei 1978* ***HMI sediment (1998) 0.2*** ***HMI sediment (1999) 0.3***	Clams from Control estuary 0.1–0.2 Clams from Hg-contaminated estuary 0.5–1.2 *Windom and Kendall 1979* ***HMI clam (1998) 0.1*** ***HMI clam (1999) 0.02***

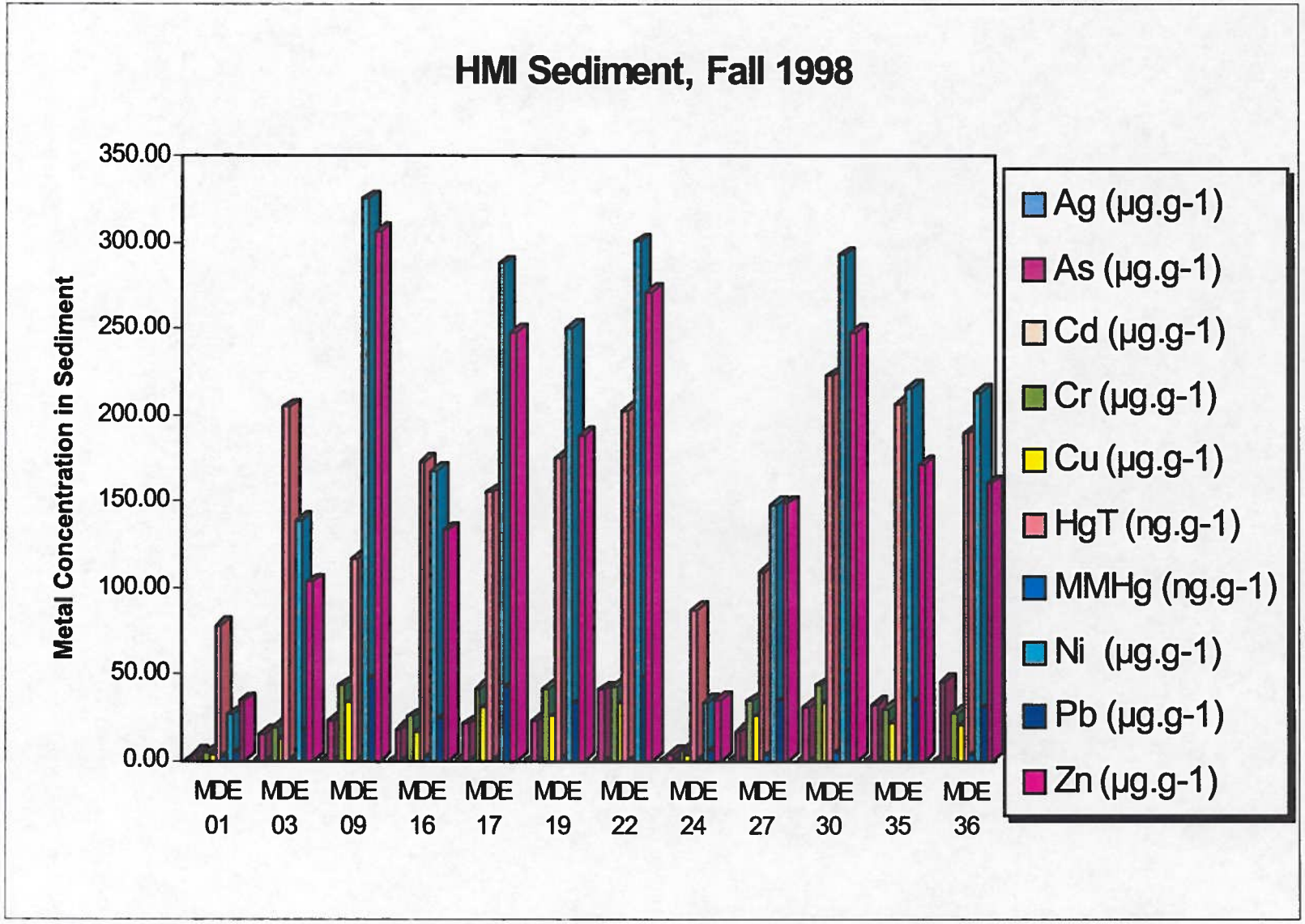


Figure 4-2: Average trace metal concentrations in sediments around HMI at sites where clams were present in September 1998.

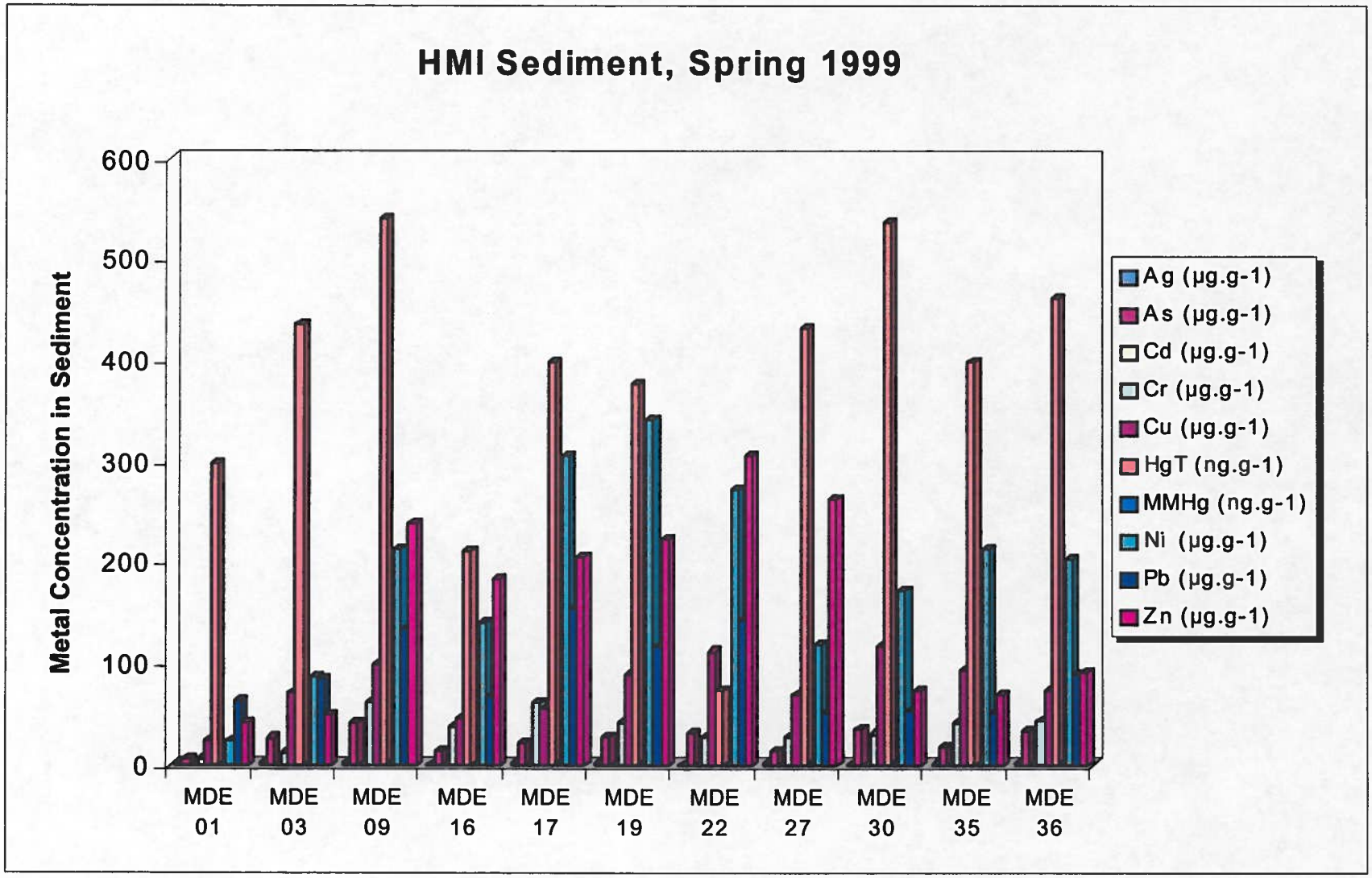


Figure 4-3: Average trace metal concentrations in sediments around HMI at sites where clams were present in April 1999.

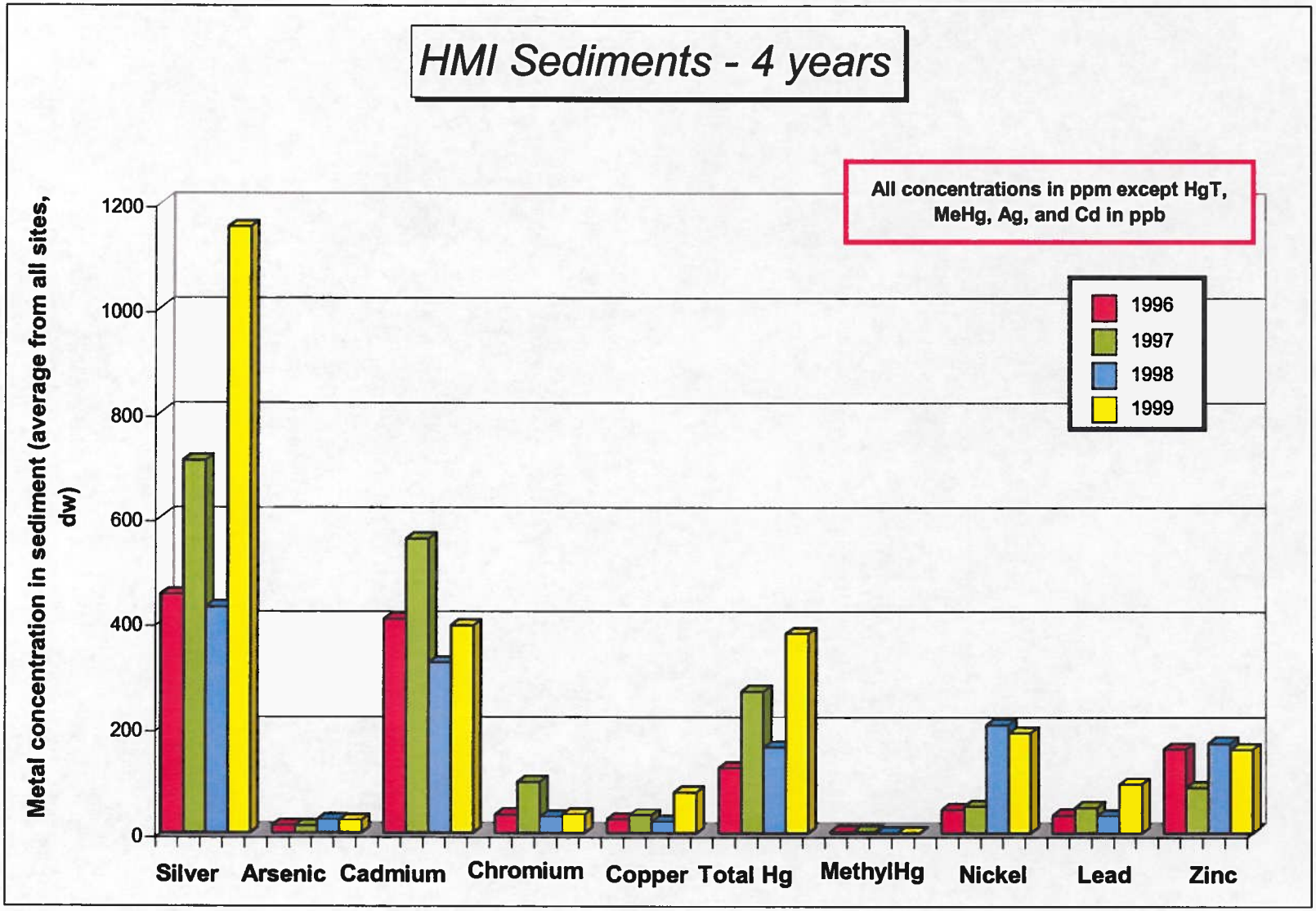


Figure 4-4: A comparison of trace metals at HMI from 1996 to 1999. Reported values are averaged over all stations.

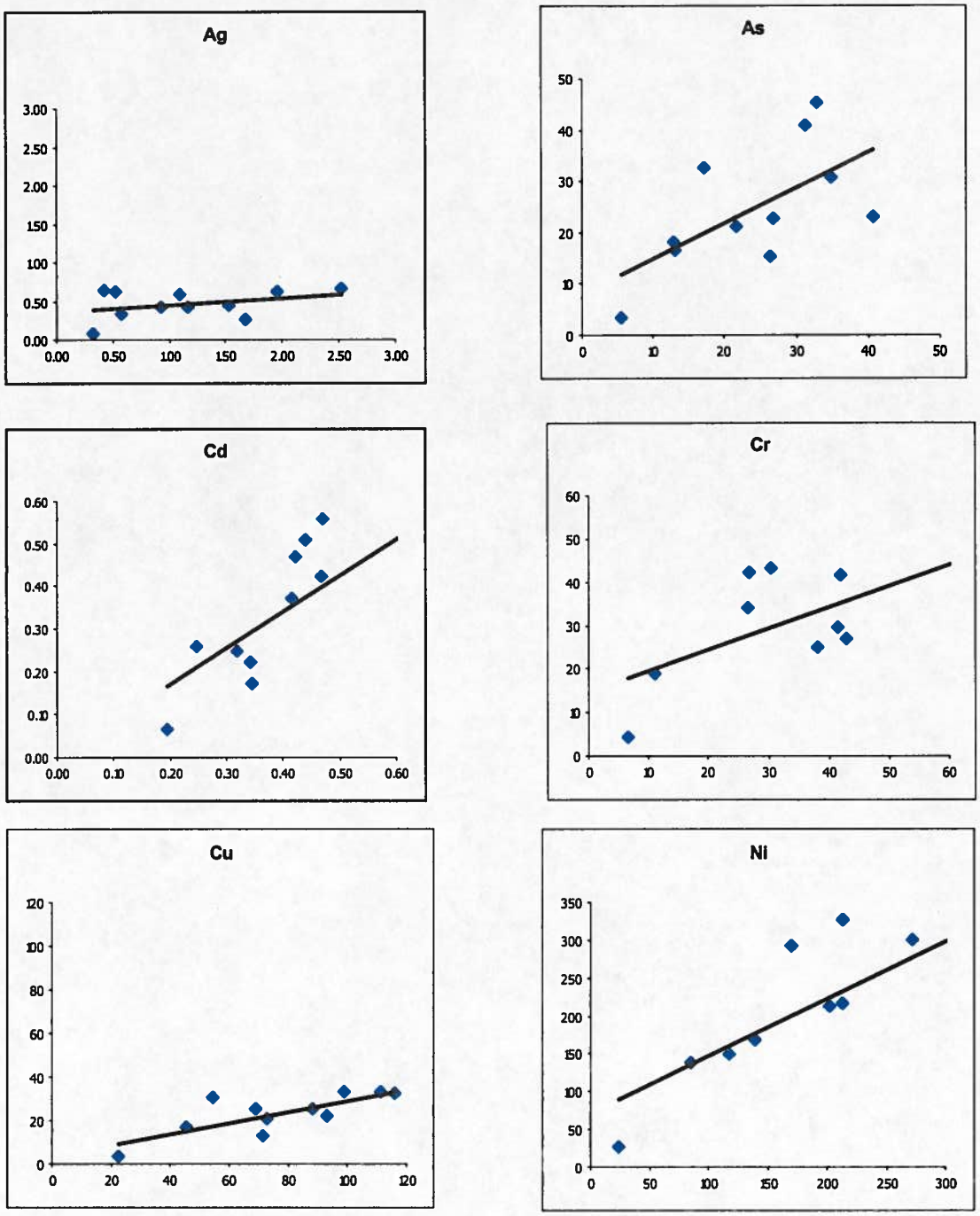
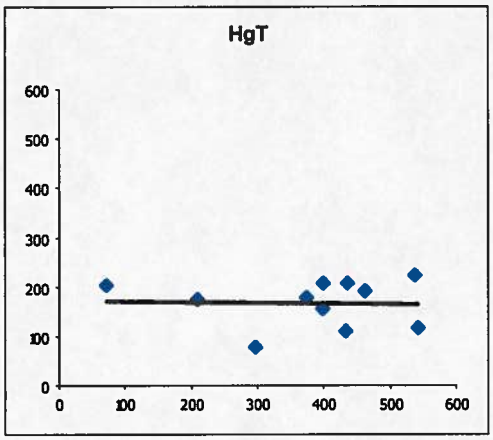
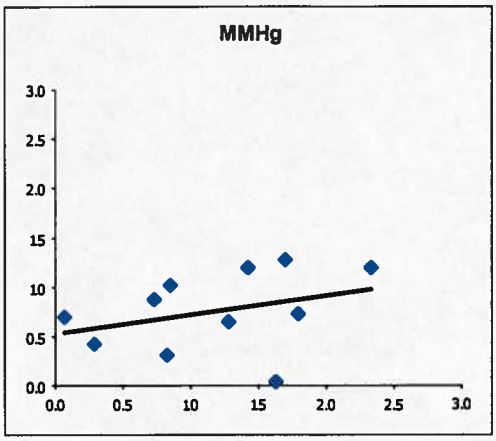
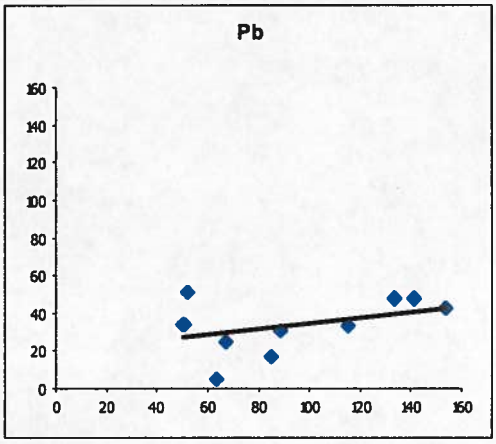


Figure 4-5: A comparison of 1998 sediment values to 1999 values for each element at each site where clams were present. Y-axis values represent 1998 data. X-axis values represent 1999 data. All data are reported as $\mu g\ g^{-1}$, except for Hg and MMHg, which are $ng\ g^{-1}$.







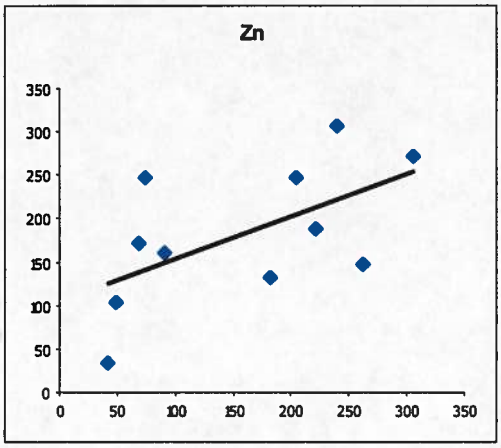


Figure 4-5, Continued.

Clams

Trace metal concentrations in clams for September 1998 and April 1999 are summarized in Figures 4-6 and 4-7, respectively. Mercury and MMHg concentrations were lowest (less than 100 ng g^{-1} and less than 20 ng g^{-1} respectively). Silver, As, Cd and Pb concentrations were also low (less than 5 μg g^{-1}). Chromium, Cu, and Ni concentrations were higher and ranged from 10 to 50 μg g^{-1}, with one notable exception discussed below. Zinc levels were the highest at approximately 140 μg g^{-1}.

The relationship between the 1998 and 1999 individual trace element concentrations in clams is shown in Figure 4-8. Trace element concentrations in clams were in good agreement between the two years with the exception of Cr (Figure 4-9). Chromium concentrations in clams

were eight times higher in 1999 than in 1998, although sediment concentrations both years were constant (35.3 and 31.8 $\mu g\ g^{-1}$ respectively). Interestingly, Cr concentrations in clams also varied greatly from 1996 to 1997, although in this case there was an increase in sediment borne Cr in 1997. Whether this difference merely reflects interannual differences or if these differences are due to changes in Cr loading to the system should be further pursued. There is the potential that Cr is being released in a reduced form in anoxic groundwater and lost from the site. Losses of redox sensitive metals with groundwater should be one of the aspects of the proposed groundwater study.

When compared to concentrations in clams (*Rangia*) sampled at Poplar Island, MD, trace metals concentrations in HMI clams are slightly higher, but still comparable to those found in the Poplar Island clams (Dalal et al. 1999). Trace metal concentrations were generally lower than those found in Galveston Bay (Morse et al. 1993) where concentrations in oysters *(Crassostrea virginica*) were measured. Even given expected species differences the results suggest that clams from the HMI area have low to moderate metal levels.

Bioconcentration factors (BCF's, the ratio of metal concentrations in the clam to the metal concentration in the sediment) in clams were fairly consistent between years (Figure 4-10). The exceptions were Cr, which had a much higher BCF in 1999, and Ag and MMHg, which had a much lower BCF in 1999 than in 1998. The differences for Ag and MMHg reflect an increase in sediment bound Ag and MMHg without a concomitant increase in clam Ag and MMHg levels. Methylmercury sediment concentrations vary seasonally in sediments (Bloom et al. 1999), while tissue levels do not because of slow depuration kinetics (e.g. Mason et al. 2000). Silver levels in sediment appear to fluctuate more than other metals (Fig 4-4), and thus slow desorption kinetics of Ag from clams could also account for their fluctuating BCF values. The increased BCF for Cr reflects the much higher Cr concentration in clams in 1999.

In general, bioconcentration factors for trace metals in clams fell into three categories:

1) Metals which did not bioaccumulate (BCF < 1; As, Cr, Cu, HgT, Pb, and sometimes Ni);

2) Metals which accumulated in moderate amounts (BCF between 1 and 6; Ag, Cd, Zn, and sometimes Ni); and

3) Methymercury, which had BCF's of greater than 10.

These results agree with those of Wang and Fisher (1996), who found moderate assimilation efficiencies for Ag, Cd and Zn in the mussel *Mytilus edulis*, another suspension feeding bivalve. All three metals have an affinity for sulfur ligands and proteins, and may bind with metallothioneins once they are consumed (Roesijadi 1992). The high BCF for MMHg may reflect its uptake from the clam's food source, as the sediment MMHg concentrations are quite low. Our studies have shown that MMHg in algae is much more bioavailable than MMHg in

higher organic content sediments (Mason and Lawrence 1999; Lawrence and Mason, in press). This is not true for inorganic Hg, nor for the other trace metals.

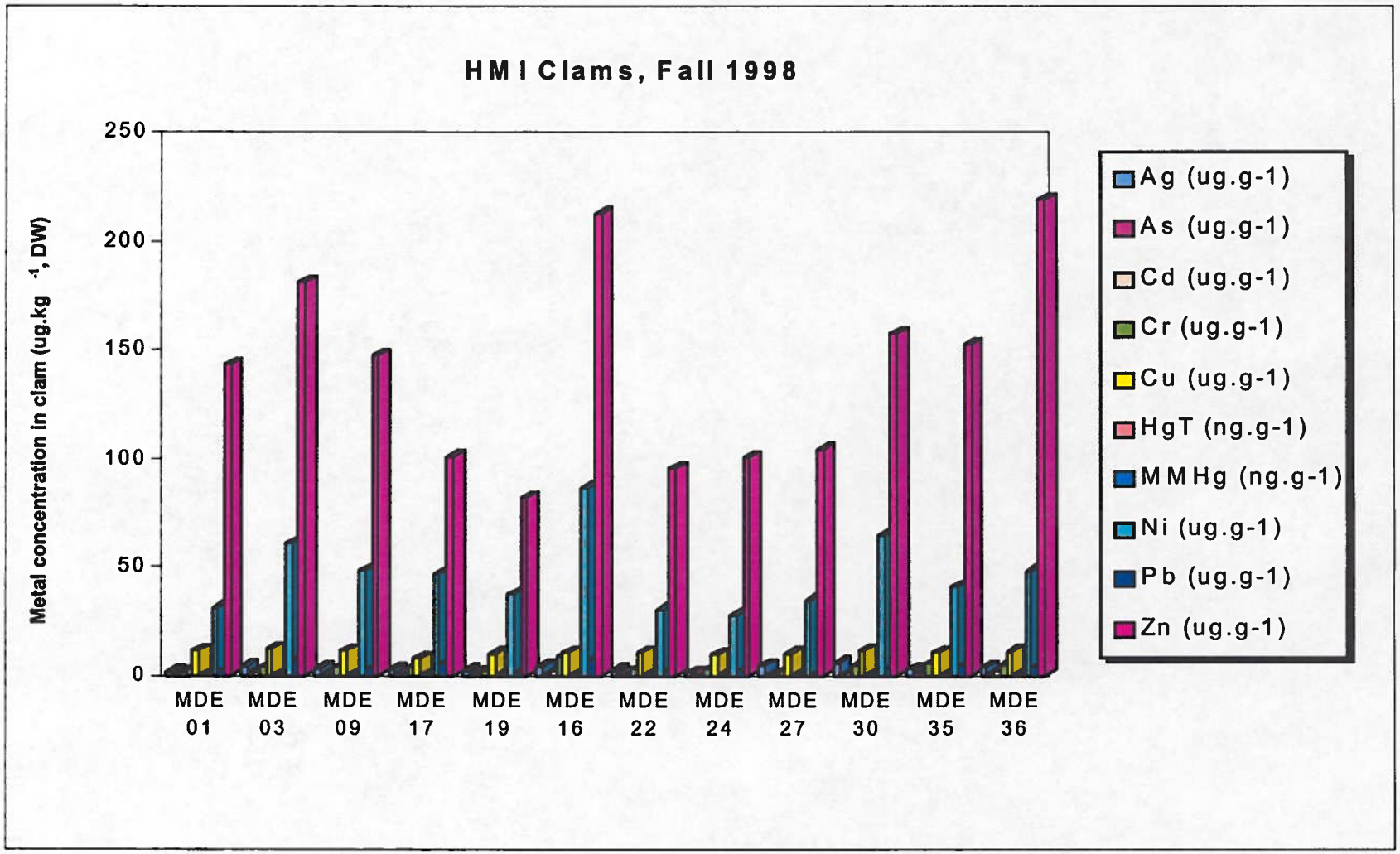


Figure 4-6: Trace metal concentrations in clams from HMI, averaged by site, in September 1998.

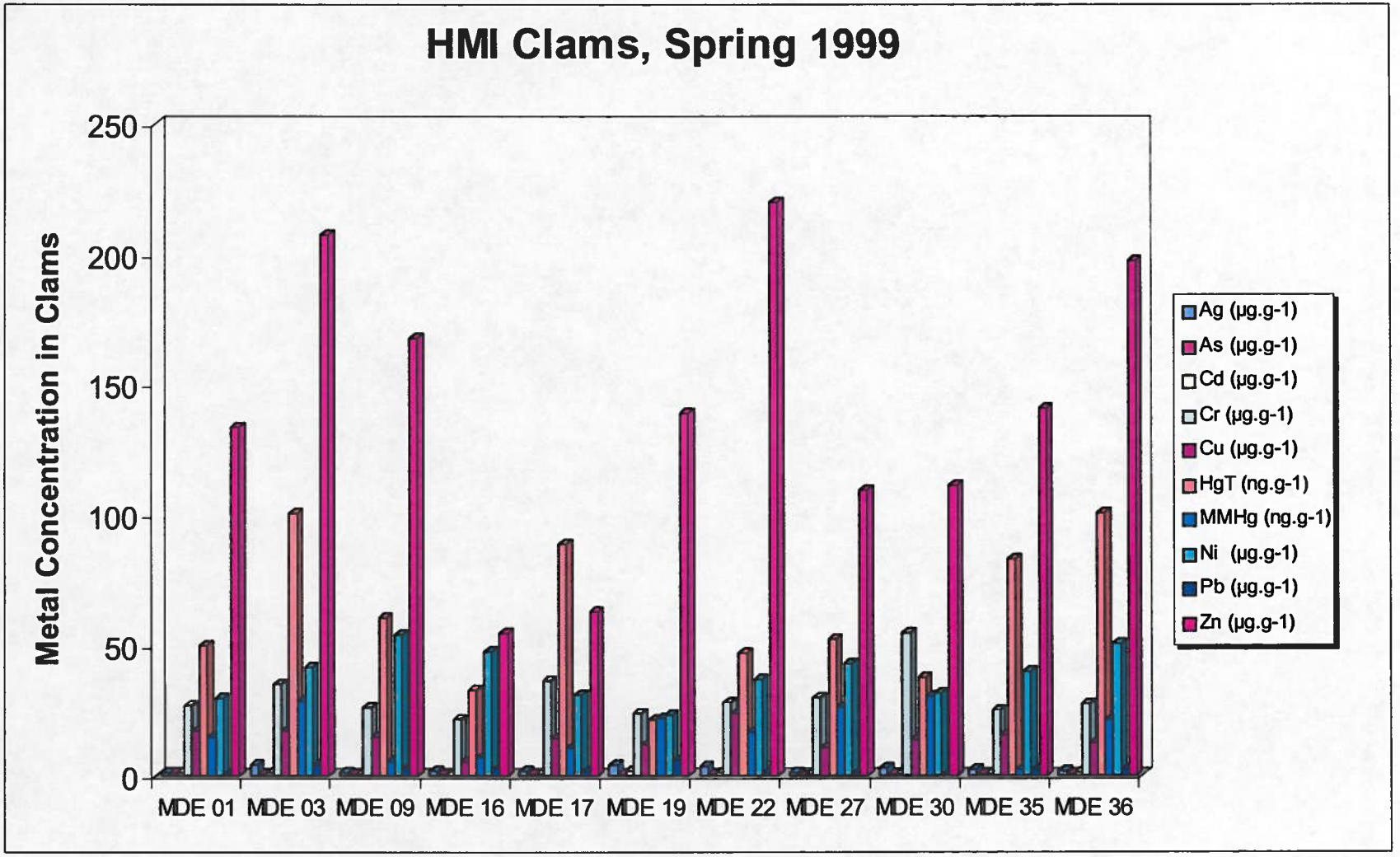


Figure 4-7: Trace metal concentrations in clams from HMI, averaged by site, in April 1999.

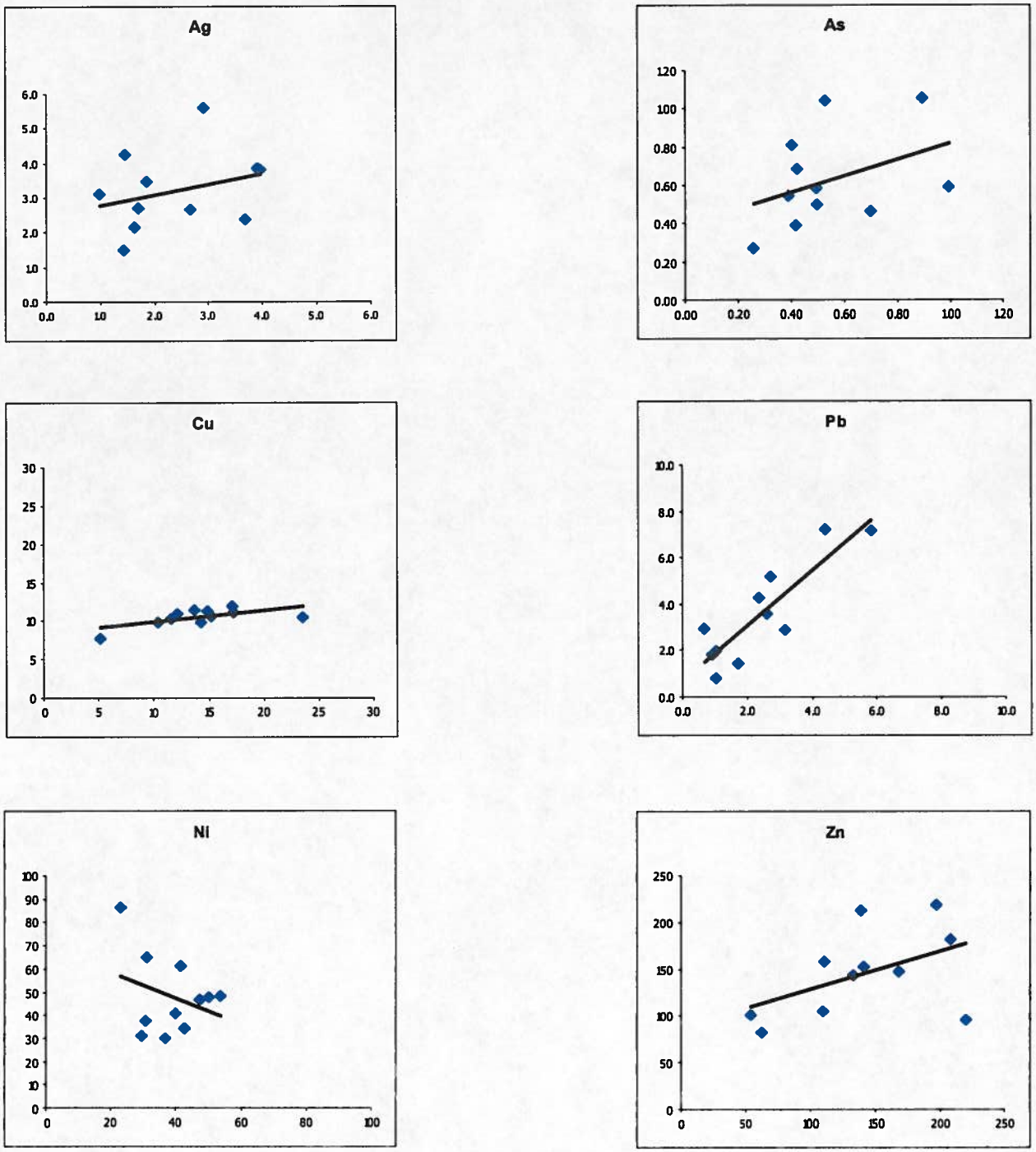
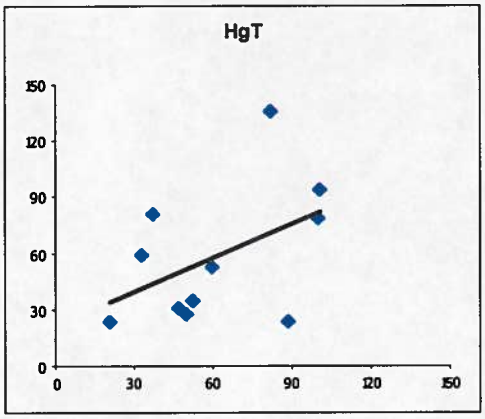
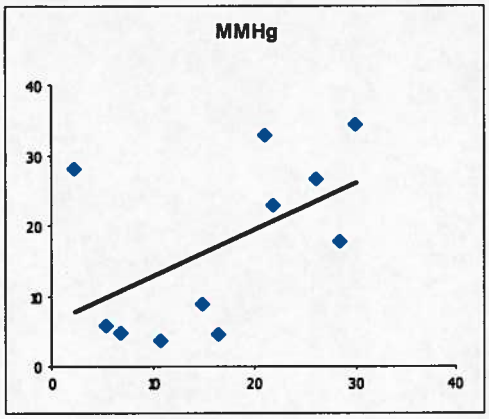
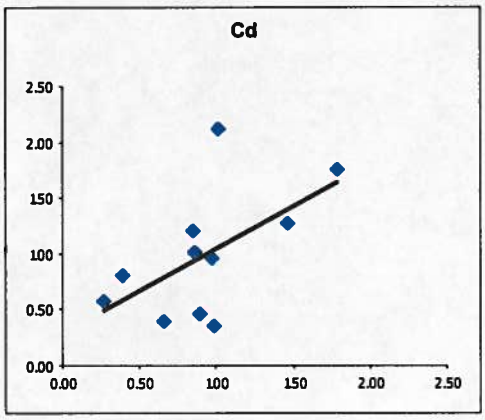


Figure 4-8: A comparison of 1998 clam values to 1999 values for each element at each site. Y-axis values represent 1998 data. X-axis values represent 1999 data. All data are reported as μg g^{-1}, except for Hg and MMHg, which are ng g^{-1}.







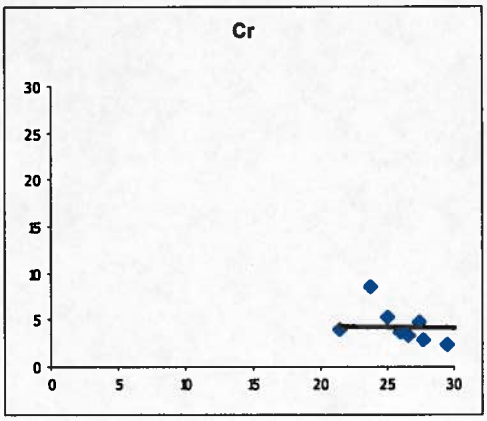


Figure 4-8, continued.

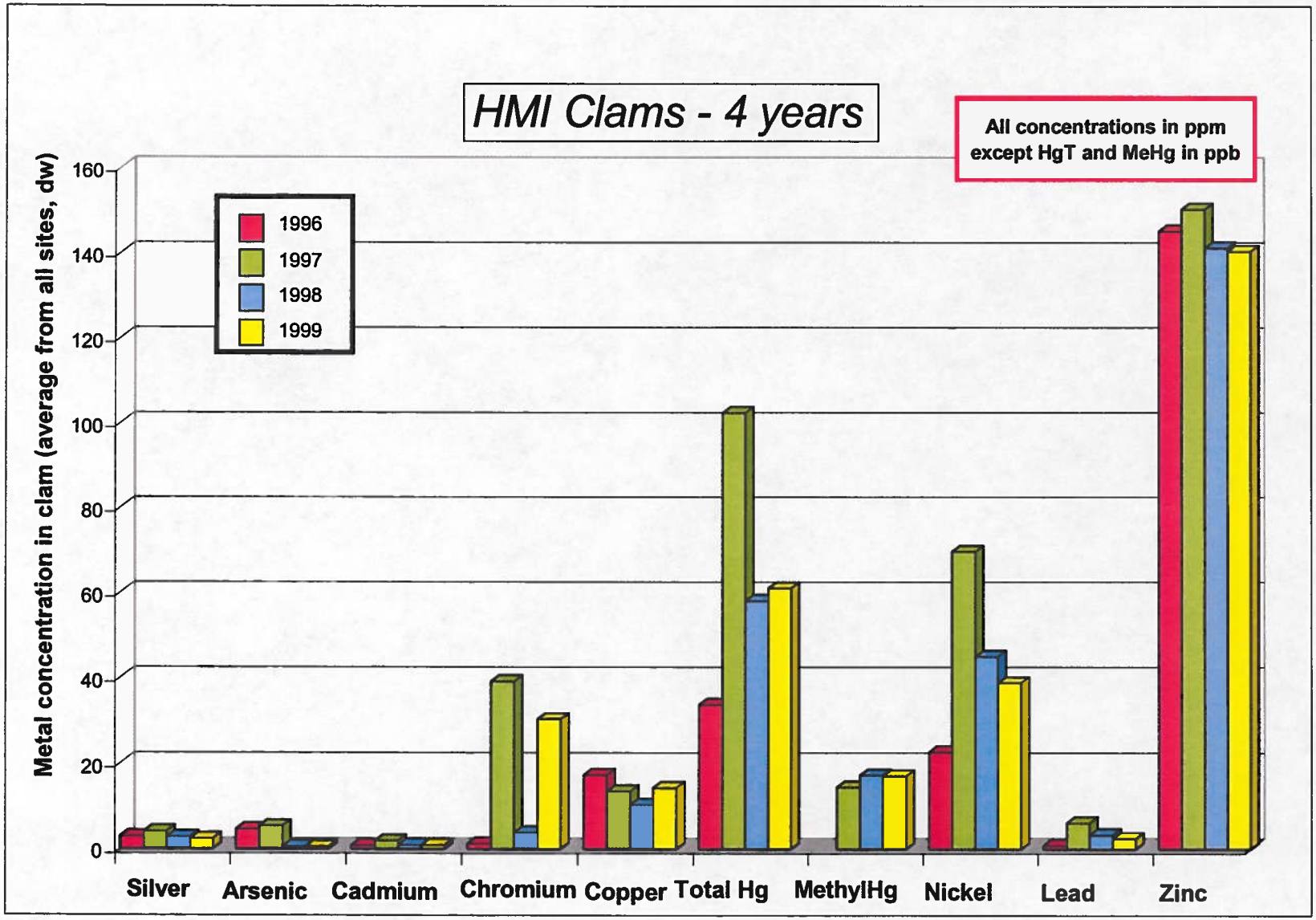


Figure 4-9: Average trace metal concentration in clams from HMI, over four years.

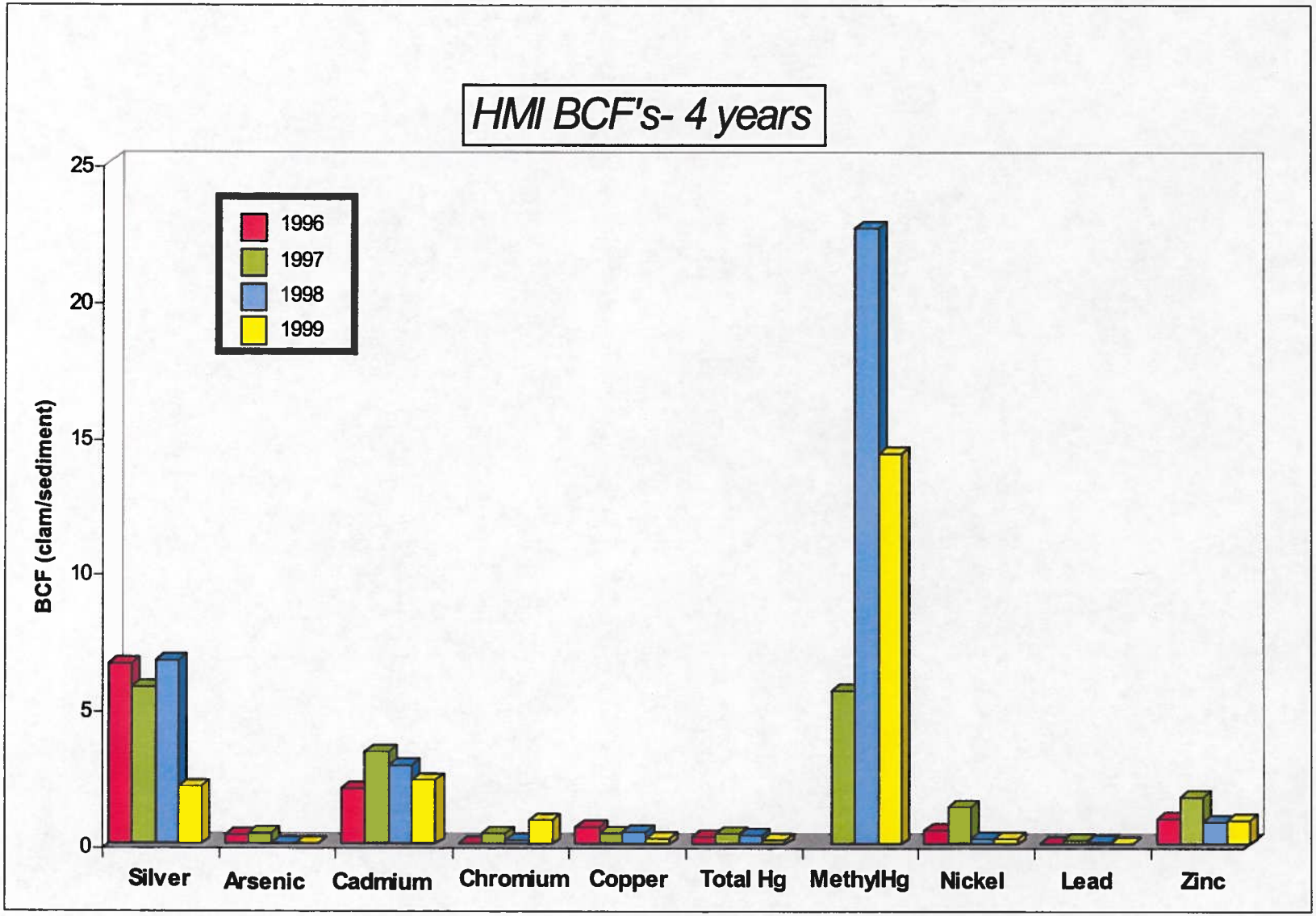


Figure 4-10: Average bioconcentration factors (metal concentration in the clam/metal concentration in the sediment) for clams from HMI from 1996 to 1999.

Organic Contaminants

PAHs in Sediments

In 1998, concentrations of total PAHs in surficial sediments surrounding HMI ranged from 280 to 5800 ng/g dry weight, and averaged 3260 ng/g-dry weight (Figure 4-11). In 1999 total PAH concentrations averaged 3070 and ranged 200 to 5620 ng/g dry weight. PAHs are not enriched above regional background levels at any of the stations immediately adjacent to the Hart-Miller Island facility. The average total PAH concentration is approximately 2.5 times the geometric mean concentration of total PAHs in northern mainstem Chesapeake Bay sediments above the Potomac River mouth (total PAH geometric means of 1090 ng/g; Nakanishi 1996). However, it is also orders of magnitude lower than PAH concentrations measured in surficial sediments in the impacted Baltimore Harbor and Back River systems, where total PAH concentrations ranged from 116 to 47,260 ng/g-dry weight and averaged 11,460 ng/g-dry weight (Baker et al. 1997). In fact, spatial analysis suggests a large gradient in PAHs (and other analytes) along a downstream transect in the Back River, leading to the Hart-Miller Island Facility.

PAH concentrations in surficial sediments around the Hart-Miller Island facility are all below the 'Effects Range - Median' concentrations published by Long et al. (1995). ERM is a statistically-derived sediment guideline represented by a concentration above which adverse biological impacts were observed in 50% of the studies.

PCBs in Sediment

In 1998 total PCB concentrations in sediments averaged 61 ng/g dry weight and ranged 8 to 105 ng/g dry weight. Total PCB concentrations in sediments collected in 1999 averaged 56 ng/g dry weight and ranged from 5 to 132 ng/g dry weight (Figure 4-11).

PAHs in Clams

Concentrations of organic contaminants in *Rangia* tissue are detailed in Figure 4-12. In 1998 concentrations of total PAHs (sum of 42 individual analytes) in *Rangia* tissue ranged from 9 to 111 ng/g-wet weight, and averaged 24 ng/g-wet weight. Total PAHs in *Rangia* tissue in 1999 averaged 44 ng/g wet weight and ranged from 13 to 80 ng/g wet weight. Thus, concentrations of organic contaminants in biota around the Hart-Miller Island facility are low and less than predicted in the equilibrium partitioning model. Calculated PAH biota-sediment accumulation factors average less than one across the Hart Miller sites, and are less than 0.2 for higher molecular weight analytes such as benzo[*a*]pyrene (Figure 4-13).

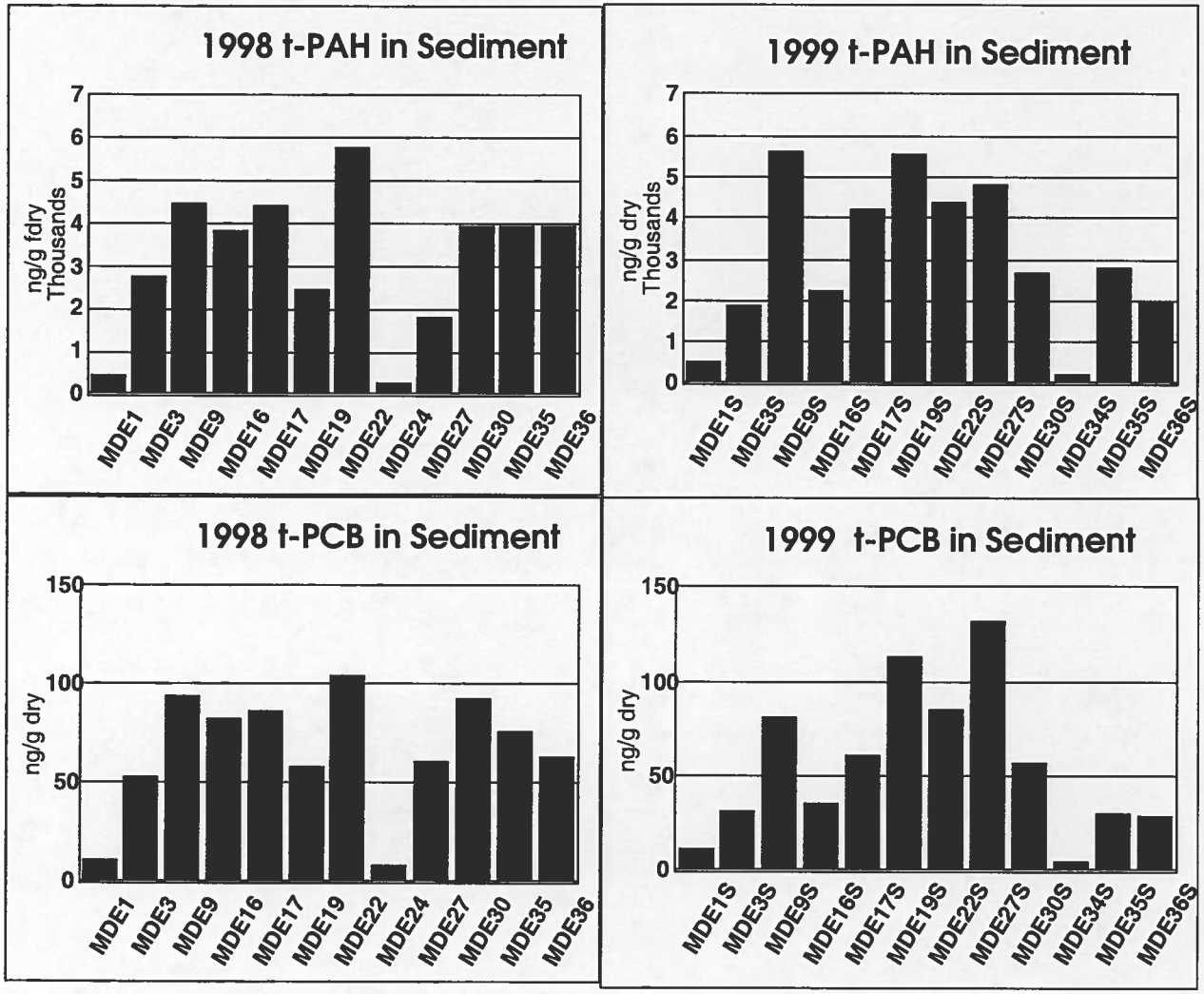


Figure 4-11: Total PCB's and PAH's in sediment around HMI in 1998 and 1999. Note that the station designations refer to large (B) or small (S) clams or to combined (C) average values.

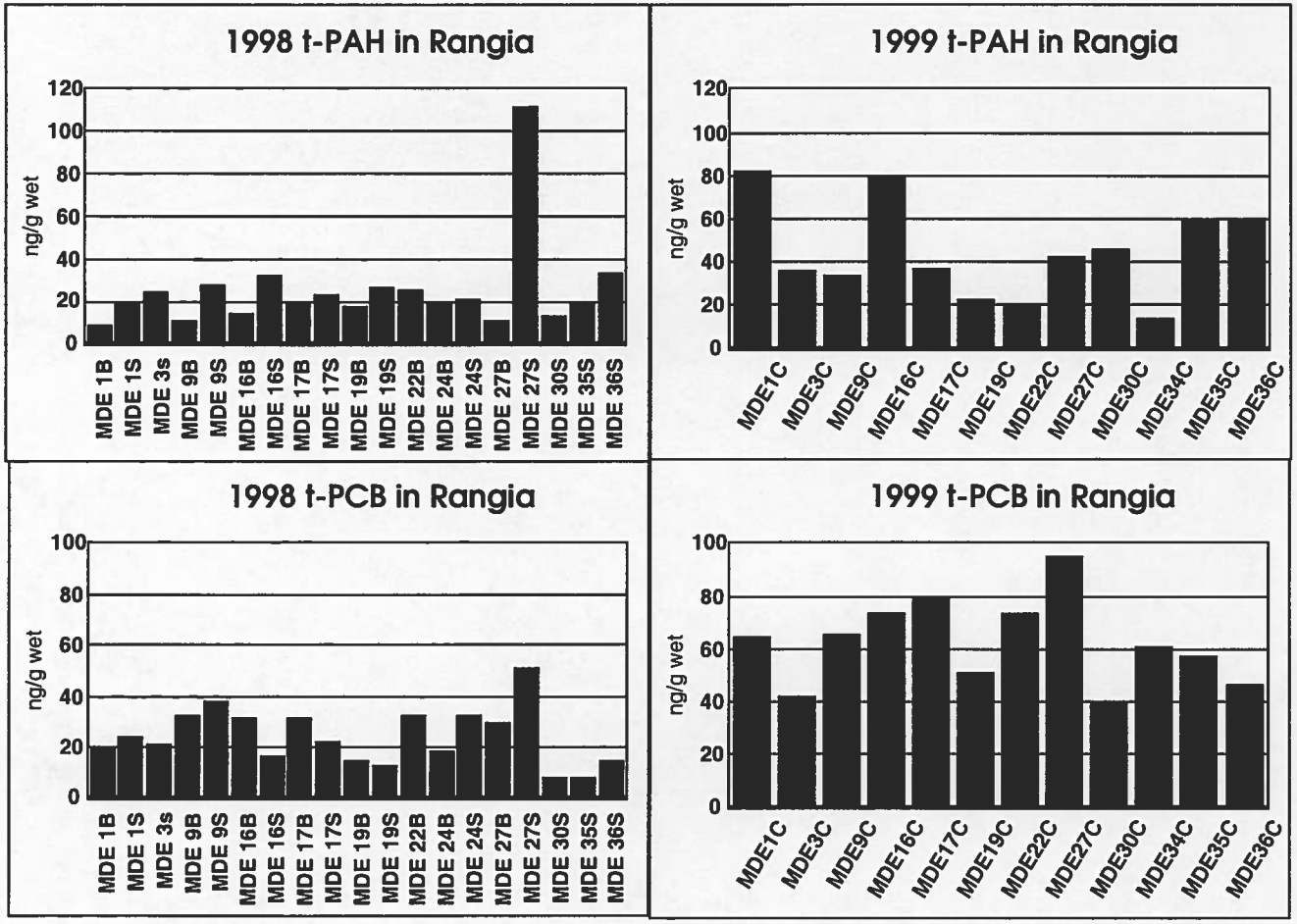


Figure 4-12: Total PCB's and PAH's in clams from HMI in 1998 and 1999. Note that the station designations refer to large (B) or small (S) clams or to combined (C) average values.

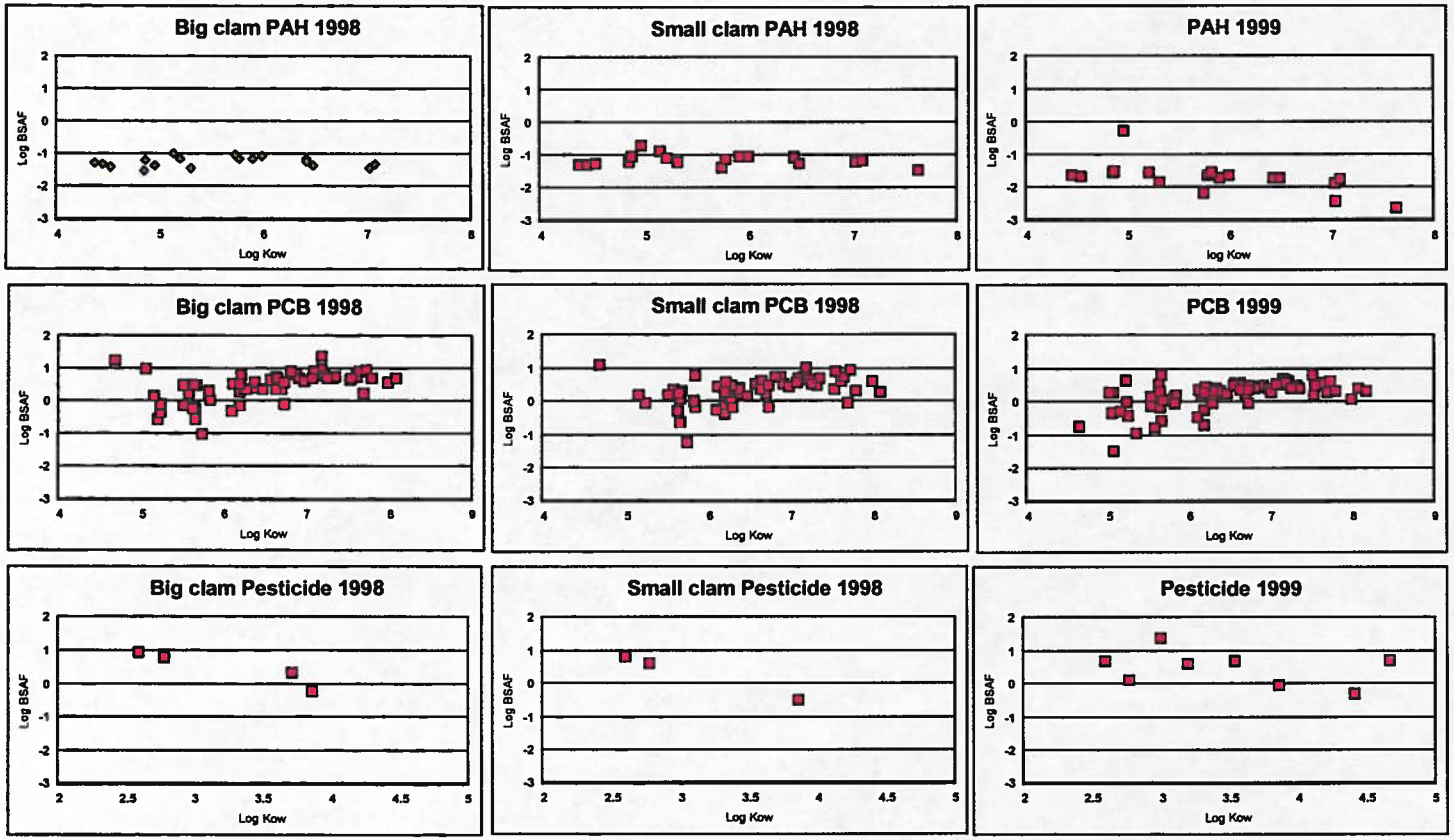


Figure 4-13: ***Rangia*'s biota-sediment accumulation factors (BSAFs) versus Log K_{ow} for PAHs, PCBs, and pesticides in HMI in 1998 and 1999.**

PCBs in Clams

Total PCB concentrations (sum of 82 chromatographic peaks containing PCB congeners) averaged 24 ng/g wet weight and ranged from 8 to 51 ng/g wet weight in 1998. Total PCBs in *Rangia* sampled in 1999 averaged 62 ng/g wet weight and ranged 39 to 95 ng/g wet weight. The Food and Drug Administration (FDA) advisory level for PCBs based on human consumption is 2000 ng/g-wet weight, or 50 times greater than the PCB concentrations observed around Hart-Miller Island. These values are further evidence that Hart-Miller Island does not contribute substantially to organic contamination of the surrounding benthic population.

It is notable that the concentrations of both PAHs and PCBs in *Rangia* are at a minimum in the Fall of 1998. Measurements taken in Summer of 1996 and Spring of 1999 are on average twice as high (Figure 4-14). This trend is not related to sediment concentrations which stay the same. This increase correlates with the average lipid content of *Rangia* which increased by a factor of 4 from the Fall (0.38%) to the Summer (1.14%) and Spring (1.8%) sampling. This correlation, rather than being a cause-effect relationship, may reflect the filtering and metabolic activity of *Rangia* during the different seasons.

Pesticides

Organochlorine pesticide (OC) levels in these *Rangia* samples are also quite low, with virtually all OC analytes present at levels less than 1 ng/g-wet weight. While no quantitative guidelines exist for the protection of ecosystem health, these very low levels of organic contaminants in *Rangia* tissue are unlikely to directly impact either the organisms themselves or their predators.

Overall, for both the metal and the organic data there is little significant difference between sites for sediment concentrations and biota concentrations. While the differences given might appear substantial - for example, the near order of magnitude difference in PAH concentrations between sites (see Data Report) - the differences are likely due to changes in the sediment characteristics. The analysis by the Maryland Geological Survey (see, for example, HMI 13th Year Reports; MDE, 1998) where metal concentrations are linked to sediment characteristics is likely to have bearing on the organic contaminant distribution as well. The amount of organic matter in the sediment controls to some degree the organic concentration and the organic content is a function of grain size and sediment type. However, the differences in behavior between organic contaminants and metals is such that it is possible to find metals in locations where organic contaminants are low and *vice versa*. Clearly, the differences in concentration between sites reflect both differences in the factors controlling sediment concentration (e.g. organic content) and differences in sources. It has been suggested that Hart-Miller island is likely not the only potential source of metals and organic contaminants to this region. To gather data sufficient to account for the inter-station differences is beyond the scope of this and the previous studies. Clearly, while differences of an order of magnitude (factor of 10) likely reflect important source signatures, differences of less than a factor of 5 do not. Thus, while differences between stations might appear significant, we conclude that the overall data set does not show clear evidence of elevated concentrations of metals and organic contaminants in the sediments around Hart-Miller Island when compared to regional concentrations in this part of Chesapeake Bay.

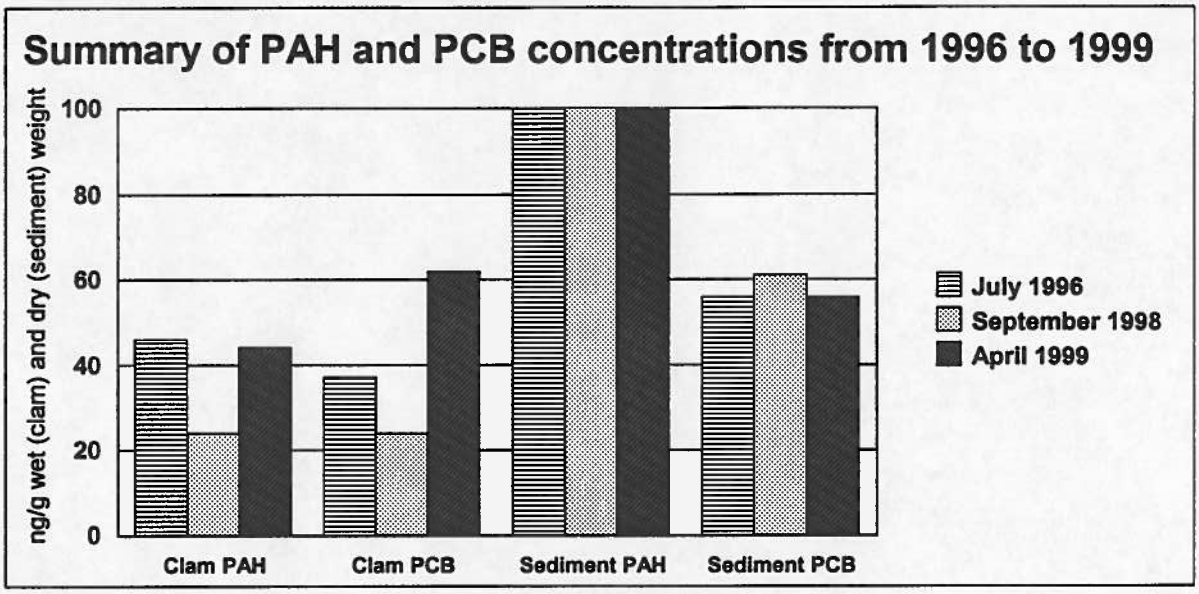


Figure 4-14: PAH and PCB concentrations in clams and sediment for three years of sampling.

CONCLUSIONS AND RECOMMENDATIONS

1. Concentrations of trace metals and organic contaminants in surficial sediments around the Hart-Miller Island facility are generally low, and are consistent with typical sediments in the northern Chesapeake Bay;

2. Concentrations of trace metal and organic contaminants in surficial sediments around the Hart-Miller Island Facility are much less than those in nearby Back River and in the Baltimore Harbor. Whether transport from the Baltimore Harbor region also contributes to the contaminant levels observed around the Hart-Miller Island facility is still unclear and is being addressed during the Year 18 study;

3. Concentrations of trace metal and organic contaminants in surficial sediment and in biota sampled around the Hart-Miller Island facility are low relative to published sediment and biota guidelines; and,

4. Seasonal differences in organic contaminant levels in *Rangia* are most likely caused by differences in the size, growth rate, and lipid content of the animals rather than temporal changes in contaminant exposure.

While the measurements contained in the Year 17 Report are not indicative of significant input and might be construed to suggest that continued sampling is not necessary, this is not recommended. However, sampling annually, or even every other year, could be a viable means of continuing to monitor as trends are likely to appear only over the longer-term. The following are the recommendations for future work:

1. Continue to collect sediment and biota samples as measurements of loadings in organisms to provide insight not apparent from sediment analysis alone; and,

2. While seasonal patterns occur, it is probably not necessary to continue to sample bi-annually.

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